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Submersible Packaging Techniques

J. H. Townsend

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PROBLEM

Certain military operations require that sophisticated electronics, designed as ground infantry electronics, be used and transported underwater. Previously, this involved using special transport cases or submersion bags. The alternative has been to design special equipments for use by the relatively limited community that operates in this environment. Transportation bags have proved unreliable and susceptible to damage; and transportation cases are bulky, heavy, and often are difficult to handle during a mission. Transportation bags and cases also inhibit using the equipment during the mission-mobility phase. Special equipment designs are especially expensive to implement, because the application community is too small to reasonably amortize the nonrecurring engineering costs.

Establishing requirements for submersibility for new equipment specifications has been difficult, because no systematic method existed to evaluate the impact of imposing the requirements on costs, weight, reliability, and other factors affecting life-cycle costs for the general user population. Submersibility requirements have been reduced or eliminated out of fear of excessive impact rather than through a system-engineered approach. Alternative packaging techniques and submergence adaption kits have not been incorporated into the original design processes, so implementing submersibility requirements is either impossible or unnecessarily costly.

This task was established to develop packaging techniques that would allow using and transporting electronic equipments underwater without special preparations for transportation. These techniques were to be compatible with man-packable equipment and amenable to cost-effective production. Most equipments need not be used underwater, so the task concentrated on technologies that allow the equipments to be used quickly and reliably after being underwater. In addition, engineering documents were created to enable submersibility requirements to be easily and cost-effectively imposed in the acquisition process.

TASK ANALYSIS

Packaging technology requires four categories of components: enclosures, connectors, displays, and controls. Each component category was analyzed to assess environmental susceptibilities, materials, and manufacturing impacts, reliability and maintainability effects, and requirements of emerging technologies. The mission profiles were analyzed to determine reasonable environmental extremes; and, in some cases, components were tested to determine their ability to withstand submergence. Information was collected to support cost analyses (relative cost impacts rather than absolute costs). The operating depth (plus engineering tolerances) was assumed to be 100 meters (approximately 300 feet).

The types of equipments that are of interest under this investigation include communications, navigation equipments, and other sophisticated units that are generally used by ground military personnel. Using these equipments in a submergence environment usually constitutes an application beyond the engineering design requirements imposed in development. Nevertheless, standard specifications applied to such equipments may exhibit performance levels approaching those required for the operations of interest in this task.

The primary specification for electronics enclosure technology is MIL-STD-108. MIL-STD-108 levels of specification for submersibility are submersible or open-submersible (free flooding) to 15, 50, or 1600 feet. Submersibility requirements beyond 1600 feet or to otherwise undefined depths must be handled by individual equipment specifications. The requirement levels of MIL-STD-108 originated in the early 1950s and have not kept up with changes in operational capabilities. MIL-STD-108 is not easily tailored in its present form and is not intended for component parts. The changes MIL-STD-108 needs to overcome these deficiencies are not too extensive.

The primary component specification for environmental performance is MIL-STD-202. MIL-STD-446 covers environmental requirements for electronic parts but fails to cover immersion or submersion. Thus, MIL-STD-202 is the only standard source document, and it stands without application guidance relevant to equipment design. There are several terms applied at the component environment level relating to equipment submersibility performance: hermetic, immersible, watertight, and sealed. Hermetic seals are intended to keep out humidity, but they can provide a higher level of performance if the component design can take the physical pressures. (This is frequently the case for small components, since the other requirements for physical enclosure exceed the pressures actually encountered.) Immersible and watertight seals also imply design features that afford some degree of submersibility; however, the design test does not at all guarantee the capabilities required in this task. MIL-STD-202 METHOD 112 specifies five conditions of seal test with several allowed procedural variations. Only Test Conditions C and E directly test seal requirements to overpressures such as those encountered in the submerged component environment. "Hermetic" devices are tested with Test Condition C. In general, the individual component specification is the sole source of sealing requirements; component specifications were reviewed on a sample basis, revealing no consistent seal specification level.

The summary of this issue is that neither equipment specifications nor component specifications directly address the operational performance requirements at issue in this task. Nevertheless, many components can meet or exceed the implied requirements because of other factors inherent in their design (material or structural characteristics that exceed the seal requirements and that must be included to meet other basic design requirements). This fact implies that (1) inexpensive modification kits are feasible for those units subjected to the submersibility requirements, and (2) a prior statement of submersibility requirements might lead to new equipments with inherent capabilities at little or no additional cost over the base design. A method of component specification for submersibility performance is required to make the equipment design task feasible and cost effective. A change to MIL-STD-202 METHOD 112 is required to provide a consistent performance baseline.

PROCEDURE

Candidate technologies were drawn from those used in deep submergence work, ocean oil drilling, commercial diving, and emerging packaging technologies. The candidates were sorted and analyzed by packaging function, i.e., enclosure, connector, control, or display. Analyses were tempered by the suitability of the technology for the generic applications. Several sample equipments were used as "straw-men" to promote the analyses: AN/PRC-104, AN/PRC-77, AN/PSC-3, AN/PSQ-4, and AN/PSC-2. None of these equipments is necessarily ever going to be used in the operating environments defined for this task. However, they strongly represent equipment packaging designs of different ages, complexities, and functions relevant to our interests. The various components used in these equipments were identified from parts lists, screened against their specifications, and analyzed individually as well as being part of an overall design package. Appropriate items were selected for submergence tests conducted in 25-foot increments to 300 feet. The items tested were subjected to the test pressures for 1 hour and examined for damage or leakage. In some cases, the test components were mounted in a test enclosure, allowing pressure to be exerted only from the side designed to be exposed. The results showed that seals specified for reduced levels of immersion could pass submersion requirements up to 300 feet, as long as they were undamaged and not excessively worn.

FINDINGS

ENCLOSURE TECHNOLOGIES

Most of the equipments analyzed are characterized by a roughly rectilinear case with large flat surfaces. Typically, the front panel and the two largest surfaces can be removed for maintenance. These large access covers are stiff enough to take drop shock and other abuse, but not sufficiently rigid to take the total pressures of submergence without being modified. Such a modification can be as simple as redesigning the sealing gasket or replacing the cover with a stiffer one. Front panel problems are most likely to occur around the penetrations for displays, controls, and connectors.

Often equipments are comprised of multiple units plugged together. This feature provides additional flexibility and improves field maintenance, but it compounds the submergence seal problem.

The single most difficult enclosure problem is the battery case and its interface to the main unit. The battery case typically has an environmental seal vent, and the vents tested did not seal to 50 feet. Should salt water leak into the battery compartment or into the connector interface to the main unit, the battery would surely fail, possibly explosively in improperly protected designs. A properly protected design provides a gasket seal to prevent leakage and also fuses the battery terminals internal to the battery case to prevent battery outgassing if a connector should short. A vent seal capable of withstanding the submergence pressures and also capable of properly venting battery outgassing is not currently in inventory. However, the technology exists through commercial sources to provide the required seal.

The task was to investigate open-submersible options as well as traditional packaging methods. Although problems with corrosion in water traps on circuit cards and internal connectors can occur, they can be solved by using new conformal coatings that are nonacidic silicone-based compounds. These conformal coatings allow maintenance, but they inhibit thermal dissipation and do not provide structural protection against submergence pressures. To test the potential problems caused by pressure, two types of large hybrid electronics modules were tested. Both types of modules had been previously qualified to the hermetic seal requirements of MIL-STD-883. These hybrid module packages are the two largest standard configurations offered commercially, being four times larger than the largest sealed module used in any of the comparison equipments. All of these packages passed submergence to 100 feet without failure. There was only a slight amount of deformation of a module lid on the largest of these packages (2 by 1.5 inches) which was well within the capabilities of the edge seals. At submergence to 175 feet, the lid deformation was sufficient to cause cracks in the solder seal of the lid and to break the hermetic seal. A secondary silicone seal was tested over the solder seal and was found to perform without failure to the full pressure of a 300 foot depth. This demonstrates the capabilities of hybrid technology to support these submersion requirements. It also shows that open-submersible options are viable when allowable by other equipment design considerations.

If equipments were being designed specifically for the user community that originates the submergence requirements, the recommended packaging technology would be the cylindrical and spherical packaging forms commonly used for diving and deep submergence applications. However, the electronics equipments under consideration are inherently of great benefit to the broad infantry user. For the following reasons, this broader community has a natural preference for the rectilinear packaging commonly found: cost, ease of access for maintenance, adaptability to different mounting configurations (manpack, vehicle, or shelter), and compatibility with manpack mobility configurations. Also, the electronics functions to be enclosed are more complex and more user-interactive than the usual equipment found in underwater applications; therefore, the requirements for displays and controls usually would exceed that which is practical for a cylindrical package.

Aluminum has been the material of choice for external enclosures for the following reasons: cost, light weight, thermal performance, flexibility and ease of manufacture, ruggedness, shielding capabilities, paintability, tolerance control, and a host of other considerations that play a role in individual designs. Alternative materials include advanced composites, structural ceramics, aramid papers, titanium, and steel. While each of these alternatives has performance features that may exceed aluminum in one way or another, none of them has the balance features exhibited by aluminum. Even excluding cost as a consideration, aluminum would still be the material of choice for the strawman equipments. Some of the materials are costly even in native form. They become more expensive when worked into a design form. Undoubtedly, these costs will come down as these materials find wider applications and enjoy manufacturing maturity; nevertheless, aluminum will probably continue to be the prime choice for the enclosures of the equipment types considered in this task. However, if one considers design modifications to infantry electronics for submersibility requirements, elements of the modification may benefit from these material alternatives. For instance, the large aluminum access covers of the case are usually not stiff enough for submergence. Thus, these covers might be replaced by an aramid paper honeycomb with a thin plate backing. Such an approach would make the cover three times thicker and considerably stiffer, but the weight would remain about the same. The cost of the new cover might be five times as much as the old cover, but it would still be in the "dollars" category as opposed to "tens or hundreds of dollars" category. Even in this example, such a change cannot be made without thoroughly analyzing the equipment to be modified, since the modified cover would not have the same thermal performance, shielding performance, and so on.

In other words, alternative materials and alternative geometries exist, but the traditional packaging forms and aluminum are likely to continue to be the designs of choice because of the balanced design performance that is achieved in this packaging approach. In custom designs for underwater environments or in special modifications for the limited user community, these alternatives may become viable.

CONNECTOR TECHNOLOGIES

The connectors commonly used in the equipments of interest are high density, quick-disconnect types, such as MIL-C-24642 or MIL-C-38999. The other types of connectors are rf types (N and BNC) and special types used on audio and battery/power supply connections. Connectors commonly used in submersible applications do

not have the pin densities required nor the compact design; also, there are no rf connector types available in deep submersible designs. The environmentally resistant form of the MIL connectors do have some immersion resistance when mated or when covered by the appropriate dust cover. However, this level of performance is not guaranteed to the depths of interest.

The various connector forms encountered on the sample equipments were analyzed and tested as appropriate. The audio connectors (U-183/U) were found to be satisfactory if the protective O-ring was intact on the mating connector and if care was exercised to clean the connector contacts prior to use after exposure to salt water. (This connector is not underwater mateable.) The connections to the battery and the various connectors between case components are not inherently submersible, but they are usable if the enclosure provides a proper gasket. Gasketing interunit connectors was not a universal design practice in the units sampled. The rf connectors can withstand submergence if they are mated to a suitable environmentally resistant connector or protective cap. For example, the standard dust cap for the BNC passed the 300 foot depth without difficulty. Unlike other types of connectors, rf connectors must be kept clean and dry throughout their life to ensure proper operation. Environmental caps are also effective for the high-density connectors. Additionally, at least one commercial source exists for submersible quick-disconnect connectors that use MIL-C-38999 insert arrangements; however, these connectors are not directly intermateable with standard MIL connectors. None of the standard connector technologies is mateable underwater, but no known requirement exists for submerged mateability in any of the mission scenarios underlying this task. There is a need to ensure that no false equipment conditions can occur when connectors are exposed to salt water. However, this is addressable if unused connectors are always covered by an environmental cover. In general, the potential connector problems are solvable; there was no need determined to develop a new connector technology. A need does exist, however, to provide maintenance procedures for the seals associated with connectors.

DISPLAY TECHNOLOGIES

There are two issues regarding displays: seal and underwater readability. The common types of displays in newer equipments tend to be LCD, EL, or LED. Active light emission is required for underwater readability, but this often conflicts with power consumption and covertness requirements normally encountered in the sample equipments. If underwater readability is required, an EL backlit LCD display is recommended. Seal is the more universal requirement. The older equipments use display windows sufficiently thick to take the depths of interest, although the method of mounting the window sometimes lacks integrity. The newer equipments are generally displaying much more information, and the displays are appropriately larger. A larger display area, with its greater pressure upon the window seals, requires careful design. If a modification were to be made for an equipment to provide a display seal for the desired depth, a simple gasketed plastic overpanel would be appropriate. Many of the displays surveyed could be submerged with little or no modification.

CONTROL TECHNOLOGIES

Controls present varied problems in a submergence environment. In general, the control constitutes a penetration to the enclosure that must be sealed, and the control itself has movable elements that must be sealed. The variety of controls found in the sample equipments has elements that push, rotate, and pivot across the seal boundary. The exceptional technology to this generalization is the membrane switch technology now coming into use.

Toggle switches represented in the sample equipments are readily available in sealed configurations that can pass the seal requirements. Several versions of sealed toggle switches are available as MIL-SPEC items; those identified as "environmentally sealed" are suitable for this application.

Rotary switches represented in the sample equipments are available in sealed versions that can pass the seal requirements. The individual switch specification is the only source of the seal performance information.

Pushbutton (nonmembrane) switches are available in sealed versions in only a few configurations. Those encountered in the sample equipments had been specially modified to pass immersion tests; the C-ring involved in the modification was able to withstand the pressures required.

Membrane pushbutton switches are becoming more and more common in new equipments. Because these switches are inherently momentary action, they are usually implemented with logic circuits that interpret the switch action into the desired result. The logic circuits can be implemented to make a single switch position multifunctional and to inhibit false conditions. The switch panel itself can be easily sealed to meet all of the environmental rigors, and the switch can be interfaced through the enclosure to preserve the case seal. In addition, windows can be integrated into the switch panel to serve as environmental seals for the displays. However, one problem encountered with membrane switches in a submergence environment occurs because the switches are designed for low-pressure actuation; this requires the interpretive logic to recognize an "all depressed" state and to ignore the switches, rendering the switches unusable underwater. Also, membrane switches often employ a dome under the contact surface to provide tactile feedback and a positive break-on-release action. However, excess pressure can flatten these domes sufficiently to cause a small percentage of them to invert, which shorts out the switch. Dome inversion can be eliminated by annealing the dome shape into one of the "memory metal" alloys; this must be special-ordered on the switch at an increase in cost. Another factor that reduces the use of membrane switches is their tendency to occupy a greater area per switch compared with other types of miniature switches. Thus while, membrane switch technology has many advantages for underwater exposure, such technology must be properly implemented.

Variable resistors used for volume controls and display lighting control are not normally sealed in their standard configuration; however, they can be ordered in a sealed configuration. The usual shaft seals used on variable resistors are equivalent to those found on rotary switches.

The O-ring seals used on pushbutton and rotary switches and on variable resistors are subject to aging and wear. The high-temperature environments to which the equipments are often subjected during storage or bulk transit accelerate this aging process and lead to a rapid failure under submersion conditions. This implies a need to replace the affected components at some regular interval or to suffer high failure rates. None of the equipment technical manuals examined had procedures for inspecting or replacing seals or sealed components.

Toggle switch seals tend to be more robust and less prone to aging effects on seal performance. Membrane switches can be exceptionally good performers if properly specified and constructed. The logic behind a membrane switch can provide a wide range of control functions, including volume control and display control functions.

Shaft seals and boots can be employed as independent modifications to seal control components. When properly selected, the items can provide the level of seal desired. However, shaft seals and boots are subject to damage and aging, which compromise their integrity; but unlike integral shaft seals, they are easily inspected and replaced by field maintenance personnel.

Another technology that could provide inherently excellent performance is magnetic switching. Magnetic switches (including Hall-effect devices) are currently not available in a form suitable for use for the control functions commonly required; but the technology may be worth pursuing, especially for those applications that justify use underwater.

Interrupted light-beam switching is beginning to become available. This technology can provide active control functions while submerged, with high reliability and relatively low cost. Usually the technology is implemented as part of an integrated control/display panel, but it should be possible to develop suitable small, discrete switches.

GENERAL

An ample array of technologies exists to provide the desired performance in a submergence environment, but the mechanisms to ensure their use in standard equipments is lacking. In most cases, the desired performance can be achieved at little or no cost increase if two criteria are met: (1) the designer knows in advance (through the equipment specification) of the requirement and (2) the designer is familiar with the technology options available. Analysis of the sample equipments and their specifications has shown that the first requirement is seldom met; and the second condition may not be met for lack of experience. In any case, the equipment technical manuals did not contain provisions for maintaining seals and components, which is vitally important for sustaining submersibility performance.

The trends toward smaller but more complex electronics create a challenge for control and display technologies to follow suit while maintaining a good operator interface. Especially in control technologies, these trends run counter to the sealing requirements. This suggests that some new component development work should be

accomplished to provide the smaller but more easily used controls and displays; submersibility requirements should also be considered in these efforts.

A cost-effective solution for the small community with the submergence requirement requires a concerted amount of coordination between the requiring agencies to ensure inclusion of appropriate specifications and guidance to the design agency to avoid unnecessary costs to the common user.

CONCLUSIONS

1. The technology already exists to meet submersibility requirements of most applications. However, the problem persists that these requirements must be communicated to the equipment designers in suitable specifications. In most cases, the required submersibility performance can be achieved at little (under 2 percent) or no cost impact to the end product.
2. The contractual requirements for equipment designers do not normally include the appropriate analysis and design tasks needed to achieve cost-effective submersibility performance. (This is because the requiring agency has waived, ignored, or failed to receive submersibility requirements.)
3. Submersibility performance can only be achieved if the requirements are known, included in equipment specifications, incorporated into designs, verified by testing, and documented in appropriate maintenance procedures.
4. The seal specifications for component items used in equipment designs are generally inconsistent with equipment specifications. This causes unnecessary repetitive analysis and component testing in order to meet submersibility requirements.

RECOMMENDATIONS

1. Formulate and provide specification guidance to the agencies who are responsible for acquiring equipments for users with submergence requirements. This guidance must be tailorable and established to minimize costs. A draft military handbook covering these criteria has been provided herein as attachment 1.
2. Formulate a handbook that can be cited in development contracts to provide design guidance for submergence requirements. This guidance will minimize the learning curve for designers who are unfamiliar with the unique tradeoffs required when packaging for submergence. A draft military handbook containing this guidance has been provided herein as attachment 1.
3. Generate changes to selected military specifications to enable the implementation of submersibility requirements to the desired depths. Proposed changes to several key military standards and specifications have been provided herein as attachment 2.
4. Provide specification guidance for key technologies where it does not currently exist. This is especially true of membrane switch technology. Key technologies are listed in attachment 3. Development of general specification guidance can be accomplished when the technologies find widespread application. The analyses included in attachment 1 will provide the required design information.
5. Develop miniature magnetic, Hall-effect, or interrupted-beam switch technology with suitable characteristics for underwater use. These technologies are emerging for general applications. Suitable components will be developed for submersion applications, if submersibility requirements are not waived for equipments under development.
6. Develop a family of connector caps with guaranteed submersibility performance and provide documentation in existing military specifications. The technology already exists, but components cannot be readily identified with specified submersibility performance. These components can be developed and documented, at a relatively low cost, in the parent connector specifications as part of an equipment development. This will occur if submersibility requirements are not waived for equipments under development.

**Design Guidelines for Electronics Enclosures for
Submersible Applications—Draft MIL-HDBK**

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DEPARTMENT OF DEFENSE

WASHINGTON, DC 20402

**Design Guidelines for Electronics Enclosures for
Submersible Applications**

1. This military handbook is approved for use by all Departments and Agencies of the Department of Defense.
2. Beneficial comments (recommendations, additions, deletions) and any pertinent data that may be of use in improving this document should be addressed as follows: Commander, Naval Sea Systems Command (SEA 55Z3), Department of the Navy, Washington, DC 20362-5101. Use the self-addressed Standardization Document Improvement Proposal (DD Form 1426) at the end of this document or send a letter.

FOREWORD

Electronic equipments are often required to serve similar applications in widely varying environments. When these environments are too diverse, it becomes difficult to design the equipment to provide reliable service across this diversity without incurring high development and production costs. Interservice equipment procurements have often compromised requirements for low quantity applications in order to maximize the cost effectiveness of the multiservice procurement.

This problem has been particularly true for equipments used in submersible applications. The user community with submersible requirements is small while the equipment requirements are often for general infantry use. The equipment enclosure requirements for general infantry use are usually specified as "watertight" or "submersible—15 feet." These requirements are perceived by many acquisition managers and equipment designers to be radically different from the typical submersibility requirement of up to 300 feet. Studies of packaging requirements have shown that this is not the case. Packaging for the greater submersible requirement is usually no more difficult nor expensive than for the watertight requirement—given other standard packaging requirements.

This handbook provides guidelines, tradeoffs, and information to assist in packaging electronics equipments for submersible applications. Submersible applications with requirements of as much as 300 feet can be addressed with little or no negative impact on costs, weight, or equipment reliability. Submersible applications with requirements over 300 feet can also be addressed.

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1. SCOPE

1.1 Purpose. The purpose of this handbook is to aid in the cost-effective specification and design of electronics packaging for submersible applications. The guidance provided in this handbook is intended to allow the resulting products to be used or transported underwater without any additional protection or special preparations. Proper application of the design guidance will improve the product environmental integrity and reliability without excessive impacts on product cost, size, or weight.

1.2 Scope. This handbook provides design guidance for electronics enclosures for submersible applications. Guidance is provided for both equipments that are used in submerged applications and that are not used submerged, but that are to be transported in a submerged mode. Four aspects of packaging are discussed: housings, connectors, controls, and displays.

1.3 Application. This handbook may be used by designers of equipments and by acquisition managers. Acquisition managers should cite this handbook in development contracts and should use it as a reference tool in design reviews. Equipment designers should consider the design guidelines when establishing design tradeoffs and when selecting parts; this consideration may be made mandatory by contractual requirements.

1.4 Classifications. The following design classifications apply:

- Class 1 Equipments designed specifically for submerged use
- Class 2 Equipments designed for nonsubmerged applications to be transported in a submerged mode without modification
- Class 3 Modification kits for existing equipments to enable submerged transport

2. REFERENCED DOCUMENTS

2.1 Government documents. The following documents of the issue listed in the current issue (or other issue specified in a contract or order) of the *Department of Defense Index of Specifications and Standards* form a part of this handbook to the extent specified:

Military Specifications

MIL-E-4158	Electronic Equipment, Ground, General Specification for
MIL-B-5423	Boot, Dust and Water Seal, General Specification for
MIL-E-16400	Electronic, Interior Communication, and Navigation Equipment, Naval Ship and Shore; General Specification for
MIL-F-17655	Field Changes and Field Change Kits, General Specification for Military Standards
MIL-STD-196	Joint Electronics Type Designation System
MIL-STD-210	Climatic Extremes for Military Equipment
MIL-STD-454	Standard General Requirements for Electronics Equipment
MIL-STD-810	Environmental Test Methods

MIL-STD-889 Dissimilar Metals

Military Handbooks

**MIL-HDBK-217 Reliability Prediction of Electronic Equipment
Other Government Publications**

**NAVMAT P-4855-2 Design Guidelines for Prevention and Control of Avionic
Corrosion**

2.2 Sources of documents. Government documents are available from the Department of Defense Single Stock Point, Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. For specific acquisition functions, these documents should be obtained from the contracting activity or as directed by the contracting officer.

3. DEFINITIONS

3.1. Case. A case is the enclosure component that provides the structural integrity of the enclosure, exclusive of access covers.

3.2 Enclosure component. An enclosure component is any component that serves an enclosure function to any degree, including those components that penetrate a case.

3.3 Enclosure. An enclosure is that portion of the equipment design performing the external packaging functions (such as structure, environmental protection, electromagnetic shielding, and thermal dissipation to the environment).

3.4 Housing. A housing is the assembly of enclosure components providing the structural and seal integrity of the enclosure, including cases and access covers/panels, but excluding components (such as connectors, controls, and displays) that penetrate the case or cover.

3.5 Separable enclosure component. A separable enclosure component is an enclosure component that is designed to be easily removed from the enclosure by the equipment operator(s). The concept also extends to equipments that consist of units connected together physically, each having its own enclosure. (Example: a radio transceiver consisting of a receiver-transmitter, a power amplifier, and a battery pack – the individual unit enclosures are considered separable enclosure components of the overall transceiver enclosure.)

3.6 Unit packaging. Unit packaging is a design approach employing a single case and a single case access, without separable enclosure components.

4. GENERAL REQUIREMENTS

4.1 Design analysis. Design analyses supporting the submersible requirement must be performed to the degree defined for the equipment design class, as a minimum.

4.1.1 Class 1 designs. The design analysis shall be accomplished for each enclosure component and for the total assembly using the operational requirements for submergence as criteria. The analytical elements shall include those provided herein. The analysis shall include worst-case design operating conditions. The operating

conditions in air and the operating conditions while submerged shall be analyzed as separate conditions.

4.1.1.1 Thermal analysis. The thermal analysis shall evaluate steady-state thermal balance for operating conditions in air and submerged at maximum and minimum temperature extremes (as specified in the individual equipment specification or as derived from MIL-STD-210). The analysis shall then consider the mechanical effects of the thermal shock on the enclosure transitioning from air to the submerged condition (as considering a swimmer jumping into the water). Three thermal shock conditions shall be considered: hot air to warm water, cold air to cold water, and warm air (25°C or 77°F) to cold water. Mechanical distortions due to thermal shock shall be considered in the seal analysis (see 4.1.1.4).

4.1.1.2 Shielding analysis. The equipment shielding requirements derived from the individual equipment specification shall be evaluated to determine electromagnetic gasketing requirements and enclosure shielding effectiveness. The gasketing requirements shall be considered during the seal design in accordance with paragraph 4.2.1. Enclosure shielding effectiveness shall be considered in the selection of enclosure materials and surface treatments as determined by the materials analysis (see 4.1.1.5).

4.1.1.3 Structural analysis. The structural analysis shall include the evaluation of housing distortions by hydrostatic pressures and maintenance of structural and seal integrity when subjected to impact shock. Impact shock effects shall be evaluated separately for drop shock in air and for impact shock submerged. The analysis limits for the drop impact shall conform to MIL-STD-810 METHOD 516.3 PROCEDURE III suggested drop heights. The analysis limits for the submerged impact shall include hydrostatic pressure for the design depth superimposed on an impact of 21.6 cm/s (8.5 in/s), or terminal sink rate for the equipment configuration (whichever is less), against a hard surface with at least a 2.5-cm or 1-inch radius.

4.1.1.4 Seal analysis. Each enclosure penetration shall be analyzed for seal requirements. The seal design shall be analyzed to ensure the following properties:

- a. Hydrostatic seal performance to design depth
- b. Design assurance of proper seal compression
- c. Seal maintainability

Design assurance of proper seal compression shall include design features preventing overcompression of the seal by hydrostatic pressures or by overtightening of mounting hardware and preventing undercompression of the seal by mounting hardware accessed for normal maintenance. Seal maintainability shall include ease of inspection of the seal for damage and ease of replacement of the seal. Seals providing protection to batteries, including battery compartment vents, shall be capable of hydrostatic seal performance of at least 1.5 times the design depth.

4.1.1.5 Materials analysis. Each component that is subject to submersion (including leakage paths) shall be analyzed within the design to minimize galvanic couples to mating components; unless otherwise specified, the dissimilar metals requirements of MIL-STD-889 (from MIL-STD-454 REQUIREMENT 16) shall apply. (NAVMAT

P-4855-2 also provides some useful information for the prevention of corrosion.) Component materials shall also be reviewed for compatibility with exposure to solvents and decontamination solutions.

4.1.1.6 Component analysis. Component analysis shall consist of a review of the individual component specifications and requirements. All components that penetrate the housing(s) shall be included. Specified component seal performance shall be compared against the submersibility requirements for the equipment.

4.1.1.7 Reliability analysis. The reliability analysis shall be accomplished in accordance with MIL-HDBK-217 PART 2 after the thermal analysis and using worst-case thermal conditions. Design changes shall be analyzed and incorporated into the base analysis as they occur. The aging of seals and gaskets shall be evaluated using the specified operating and storage temperatures; the results of the analysis shall be incorporated into the equipment operation and maintenance procedures for maintaining the seals.

4.1.2 Class 2 designs. The design analysis for Class 2 designs shall be the same as for Class 1 designs (see paragraph 4.1.1) except that the equipment is in a nonoperating condition while submerged.

4.1.3 Class 3 designs. The design analysis shall be accomplished on the existing equipment design. The total packaging design and each component of the enclosure shall be included. The analytical elements shall include those provided herein. Those components that are deficient for the submersible requirement shall be redesigned for inclusion in a retrofit kit in accordance with paragraph 5.1 or in a field change kit in accordance with paragraph 5.2.

4.1.3.1 Structural analysis. Structural analysis shall be accomplished in accordance with paragraph 4.1.1.3, except that the drop limits shall not exceed the individual equipment specification. All access covers and separable enclosure components shall be included.

4.1.3.2 Seal analysis. Seal analysis shall be accomplished in accordance with paragraph 4.1.1.4. All access covers, mountings of enclosure components, and separable enclosure components shall be included.

4.1.3.3 Component analysis. Component analysis shall consist of a review of the individual component specifications and requirements. All components that penetrate the housing(s) shall be included. Specified component seal performance shall be compared against the submersibility requirements for the equipment. Suitable replacements shall be identified for deficient components.

4.1.3.4 Functional analysis. The functional design analysis shall include all enclosure components. The enclosure functions analyzed shall include shielding, heat dissipation/absorption, shock isolation, protection from solvents and decontamination solutions, and special appearance requirements (nonreflective, camouflage, and other requirements as may be required by the original equipment specifications and drawings). The functional analysis shall determine the functional performance requirements and capabilities for each component.

4.2 Design guidelines.

4.2.1 Housings. Equipments designed primarily for underwater use normally employ unit packaging. Unit packaging has the advantage of minimizing housing penetrations and sealing requirements; however, accessibility for maintenance may be severely restricted. Equipments designed primarily for use out of water normally have accessibility requirements inconsistent with unit packaging. In general, enclosure designs should minimize housing penetrations and other design features that require seals for submergence exposure. Seals should be integrated into the housing design but remain easy to inspect and maintain. Combination seals and EMI gaskets shall not be used; the separate EMI gasket (if required) shall be wholly contained within the sealed enclosure.

4.2.1.1 Class 1 designs. Class 1 housings should incorporate integrated control/display panel technology, where possible, to minimize seals and enclosure penetrations. Enclosure components should be designed to withstand submergence individually and as part of the enclosure design. The enclosure shall be designed to allow easy and rapid cleaning with fresh water and shall not have design features that retain water after submergence exposure. The housings shall be designed to provide seal protection to connectors between separable enclosure components.

4.2.1.2 Class 2 designs. Class 2 housings shall be designed to allow easy and rapid cleaning with fresh water and shall not have design features that retain water after submergence exposure. Use of integrated control/display panel technology is encouraged. The housings shall be designed to provide seal protection to connectors between separable enclosure components.

4.2.1.3 Class 3 designs. The modified housing design shall avoid water traps or pockets. Instructions shall be provided with the modification kit for cleaning with fresh water. All modification kit components shall be capable of performing all of the functions of the original enclosure components as determined by the functional analysis (see paragraph 4.1.3.4) to the required level of performance.

4.2.2 Connectors. Standard environmentally resistant connector types exhibit a variety of seal performance requirements. In general, the seal performance is limited by the insert retention characteristic. Even when the insert retention is rated to withstand the hydrostatic pressures, the seal leakage rates may be unacceptable. Hermetic seal connectors will provide the degree of seal needed, but hermetic headers may not have the structural integrity to withstand the hydrostatic pressures beyond the connector specification test criteria (most hermetic connectors are only tested to 1 atmosphere differential pressure). Most mateable protective caps used with connectors are capable of providing an acceptable degree of seal protection even though they are designed as "dust caps."

4.2.3 Controls.

4.2.3.1 Individual controls. Most individual control functions are available in sealed component designs compatible with some degree of submersibility. Elastomeric boot seals (in accordance with MIL-B-5423) are available that will provide submersible performance for many of those components which are not sealed. Two types of seals are important to enclosure design: the sealing of the control component to the housing it penetrates and the sealing of the movable control members (such as shafts

or pushbuttons) that are exposed during submersion. A third type of seal—the seal of the internal control mechanism—is not a direct issue of submersibility design, per se. Seal of the internal mechanism increases reliability by excluding contaminants; such seals may be adequate to provide sufficient sealing for the required degree of submersibility if they have enough structural integrity to withstand the hydrostatic pressures. All three types of component seals shall be considered in design.

4.2.3.2 Integrated controls/displays. Integrated controls/displays combine external control functions, display functions, and enclosure requirements into a single assembly. The integrated approach minimizes the number of seals and simplifies assembly and maintenance in the field. An integrated control panel may or may not contain display elements, but provisions for the environmental protection of displays is included in either case. A single master seal protects all of the internal control elements and display components. (Shielding is also accomplished by a single overall shield.) Some analog control functions, such as volume controls, are not available in integrated technology directly; rather, the analog functions are replaced by switch functions that are translated to mimic the analog functions by interface logic.

4.2.3.2.1 Class 1 designs. Control elements for integrated panels in Class 1 designs are limited by the need to function while subjected to hydrostatic pressure. The control actuation shall not differ significantly between operation in air and operation while submerged.

4.2.3.2.2 Class 2 and Class 3 designs. Integrated panel control elements may be of any design that is not damaged or degraded by excessive overpressure due to submergence. The actuation of control elements by hydrostatic pressure shall not damage the equipment and shall not cause the equipment to malfunction, change modes, or degrade in any operational manner.

4.2.4 Displays. Displays include individual indicators and integrated display systems. Display components are not normally submersible, although some individual items may be capable of withstanding a submergence of several hundred feet if they are rated as hermetic and are structurally capable of withstanding the hydrostatic pressures. The housing usually provides a window to protect displays from hydrostatic pressure. Use of integrated control/display panels is encouraged.

4.2.4.1 Class 1 designs. Visible displays in Class 1 designs must be both submersible and visible while in use submerged. A suitable control of display illumination shall be provided to accommodate low-level lighting conditions while submerged and for equipment use in air; as a minimum, use in air must include the equipment maintenance conditions. Audible displays shall be operable submerged and in air. The acoustic output shall be suitably adjustable for both usage conditions. The housing/display combination shall be capable of withstanding the hydrostatic pressures of the design depth.

4.2.4.2 Class 2 designs. The housing/display combination shall be capable of withstanding the hydrostatic pressures of the design depth.

4.2.4.3 Class 3 designs. The existing housing/display design may be replaced, if necessary to meet the specified submergence requirements, by a design capable of withstanding the hydrostatic pressures of the design depth. If a total replacement is chosen, integrated control/display panel technology should be considered.

4.3 Acquisition alternatives. Submersible applications are frequently small quantity requirements of more extensive general applications. The extreme differential in quantities can generate more cost-effective approaches to the acquisition of the required equipments. The following subparagraphs discuss the tradeoffs in the primary acquisition strategies appropriate for submersible applications.

4.3.1 All equipments identical. This acquisition strategy is always appropriate when the submersible applications exceed 10 percent of all equipment requirements. In addition, this acquisition strategy is preferred whenever economically feasible. The economic differential between general applications and submersible applications will generally be negligible when the control and display technologies are heavily integrated into a single panel, the equipment packaging tends toward unit packaging, and the general applications have an enclosure requirement of at least watertight in accordance with MIL-STD-108.

4.3.2 Submersible application variant. This acquisition strategy involves the development of a distinct equipment variant for submersible applications. It is an appropriate strategy in the following situations: (1) when the development cost of the variant, plus the increased unit costs for the submersible application equipments (due to lower quantity procurements) are offset by cumulative lower unit costs for the general applications, and (2) when the concept of support for the submersible applications differs substantially from the concept of support for the general applications. This strategy may also apply when (1) the general applications have an enclosure requirement of less than watertight in accordance with MIL-STD-108, and (2) the submersible applications constitute less than 10 percent of all equipment requirements.

4.3.3 Submersible application retrofit kit. The acquisition of a submersible retrofit kit in parallel with the general application equipments is generally appropriate when the other acquisition strategies are not appropriate.

5. SPECIFIC REQUIREMENTS

5.1 Retrofit kit design. (for Class 3 requirements and designated new designs). Unless otherwise specified in the contract or order, retrofit kits should be designed to allow accomplishment of the retrofit by echelon 3 (field intermediate maintenance) maintenance technicians or by operator personnel. The retrofit kit should be designed to allow the restoration of modified equipment and the transfer of the kit to another piece of equipment. The design life of retrofit kits should be at least 6 years, assuming transfer of the kit for each equipment failure requiring maintenance beyond echelon 3 capabilities and assuming the projected operational usage for the submersible application.

5.1.1 Housings. Housing designs that are suitable for retrofit normally have seal/structural deficiencies that can be remedied by replacement of access panels and their associated seals. Large access panels often will not be sufficiently stiff to withstand submergence pressures without compromising the seal design. Often the seal design is inappropriate for submergence; this is especially true where combination seals/EMI gaskets have been employed. In general, O-ring seals should be employed; refer to Appendix A for guidance in O-ring seal design. Another common deficiency is the lack of adequate seals between separable housing components (as between an electronics enclosure and a battery pack). The following suggestions are provided to correct these deficiencies:

- Replace access covers with covers of a stiffer material (such as composites) or of a stiffer design (employing rib stiffeners).

TRADEOFF CRITERIA:

- Stiffer designs usually add as much as 100-percent more panel thickness.
- Materials and designs with added stiffness are usually more expensive than those they replace (especially in retrofit kit quantities).
- Stiffer materials do not have the thermal conductivity of the more standard aluminum panels (designs depending on heat dissipation through the panel will be adversely affected).
- Stiffer materials/designs may incur a weight penalty of 0 to 50 percent (compared to the panel replaced).
- Composite materials containing carbon (graphite-epoxy) will create a potential dissimilar metals couple with aluminum housings.
- Many stiffer materials lack substantial shielding capabilities. Shielding must be added, usually in the form of an electroless plating process.

- Replace existing gaskets/O-ring seals with seals designed for the submergence depth and for accommodating panel flexure.

TRADEOFF CRITERIA:

- Combination gaskets/EMI seals must be replaced by separate O-ring seals and shielding gaskets. This will usually require redesigning and replacing the associated cover as well.
- Unglanded gasket seals may be subject to failure by extrusion. Modifying the associated cover to provide a suitable gland or redesigning the seal/cover combination is usually the most viable solution.
- Redesigned covers may be slightly thicker overall, but weight and cost penalties should be less than 5 percent.
- Small case-to-cover gaps (0.015 inches or less) normally do not require O-ring redesign for submergence depths of 500 feet or less.

- Add O-ring seals and/or glanded gaskets around connectors between separable enclosures.

TRADEOFF CRITERIA:

- Intercase connectors are often special designs that require special adaptations for O-ring seals. Standard applications usually require some form of O-ring, but the resulting connector design may not incorporate sufficient tolerance control to maintain the O-ring integrity and may not be cost effective to change.

- Glanded seals may be feasible, but may require changes to the cases that cannot be accomplished in field maintenance environments.
- Form-in-place silicone seals may be used as a back-up; however, such seals should be considered as one-time usage items. Nonacidic form-in-place silicone formulations should be specified to prevent corrosion on electrical parts and damage to finishes. Form-in-place gaskets should not be used where the gasket squeeze can force gasket material into connectors or where the housing cases are subject to relative movement.
- A large volume may exist around the connector between a battery pack and an electronics case. In such cases, a dual-density gasket should be considered.
- Proper seal design should not adversely impact weight or cost beyond standard application requirements for submersible requirements less than 500 feet.
- A housing sleeve of titanium or reinforced composite can be fitted tightly over the entire enclosure.

TRADEOFF CRITERIA:

- The housing sleeve adds, with a relatively low weight penalty, sufficient structure to prevent excessive access-cover distortion from breaking otherwise adequate seals.
- The housing sleeve inhibits equipment access for changing batteries or other maintenance.
- The sleeve can introduce corrosion problems or thermal design problems.
- Housing tolerances can be too large to effectively design a seal between the housing and the sleeve.

5.1.2 Connectors. There are three primary concerns pertaining to connectors in a submersible application: corrosion of the electrical contacts, actuation or burnout of electrical functions, and seal through the connector. For nonoperating submersible applications, seal through the connector is the sole concern when no power is applied to the pins/sockets; it is assumed (and must be backed up by training and operator instructions) that the connector will be rinsed and dried prior to putting the equipment into service. For all other applications and when operator cleaning cannot be relied upon, the design concern is to keep the connector insert dry during submergence. The following design suggestions are provided:

- Provide suitable seals and gaskets between the connector and the housing it penetrates.
- Use hermetic environmental connectors. Hermetic series connectors have adequate seal specifications for submersible applications to depths in excess of 300 feet; however, hermetic seal requirements assume a maximum of one atmosphere differential pressure. Hermetic seal designs vary between suppliers and some may not have the structural integrity to withstand submergence

pressures, especially in the larger connector shell sizes. Specification control drawings will normally be necessary to maintain design control for submergence, even though the connectors used are otherwise standard configurations.

- Provide connector caps with suitable gaskets. Most of the "dust caps" available for various series of connectors are capable of providing submergence protection to depths in excess of 300 feet; however, dust cap gasketing designs vary between suppliers and are not routinely tested for submergence pressures. A specification control drawing will normally be necessary to maintain design control.
- When it is impractical to change a connector, it may be possible to provide a sealing collar. A sealing collar may range from a boot seal used in conjunction with a dust cap to a sheet metal sleeve threaded to receive its own cap seal.
- When an otherwise unsuitable connector must be used in a submersible application, an interface pigtail mating can be provided to that connector and terminated in a connector designed specifically for underwater use. The interface between the subject connector and the pigtail mate can be semipermanently sealed with noncorrosive silicone sealant. Connectors designed for underwater use are not intermateable with connectors used in standard applications, so a second pigtail adapter cable may be necessary to mate to the connected equipment or accessory. (This arrangement is probably most suitable for connections to terminal equipments and accessories.)

5.1.3 Controls/Displays. Retrofit kit designs can take either of two substantially different approaches to control and display submersible packaging problems: a component-by-component approach or an integrated approach.

5.1.3.1 Individual component approach. In retrofit kits, this approach is generally limited to adding boot seals (MIL-B-5423) to controls and to adding structural windows over displays. Implementation costs are generally low, but reliability can be reduced and maintenance burdens increased. Some control/display designs cannot be readily protected by discrete techniques; in this case, consider the integrated approach (5.1.3.2).

5.1.3.2 Integrated approach. The integrated approach replaces an entire panel of controls and displays with one using an integrated control/display technology. Implementation costs are relatively high, but reliability can be increased and the overall maintenance burden decreased. Ease of retrofit may depend upon the existing panel of controls and displays being easily separated from the main electronics through a connector.

5.1.4 Technical documentation. Retrofit kit documentation should include design/procurement documentation, retrofit instructions, and operations and maintenance technical manual supplements. Only documentation required by the contract or order is mandatory.

5.1.4.1 Design/procurement documentation. Design documentation for retrofit kits should generally include technical reports containing the analyses of the existing design to be retrofitted, including (but not limited to) tradeoff cost analyses, weight impact analysis, seal design analysis, and reliability impact analysis. The

procurement documentation should include the specifications and drawings necessary to procure and repro cure kits in small quantities from multiple sources.

5.1.4.2 Retrofit instructions. The retrofit kit instructions should provide (1) directions for accomplishing the retrofit and for restoring the equipment to its original form and (2) a complete inventory of all items contained in the kit that are required for the modification. The retrofit procedures should consist of detailed step-by-step instructions, amply illustrated by drawings and/or pictures, and written for a 7th grade reading level.

5.1.4.3 Operator and Maintenance Manual supplements. Supplements to the equipment technical manual(s) should include the following information elements:

- preventative maintenance instructions covering the inspection procedures for all seals.
- operator instructions peculiar to the kit or peculiar to the submersible requirement. For instance, modified instructions for changing batteries with precautions about the seals, and instructions for cleaning and rinsing connectors after exposure to salt water.
- replacement procedures for all seals and gaskets and other parts that may be peculiar to the kit.
- parts list information for all kit parts, seals, and materials. The supplement should have a caution to consult the supplementary parts list before ordering repair parts. Parts that have been replaced by the kit should be annotated.
- directions for the disposition of parts replaced by the retrofit, especially if those parts are required to restore the equipment to its original condition.

5.1.5 One-shot retrofit kits. One-shot retrofit kits are modification kits designed for use by operator personnel. Each kit consists of modification materials and appropriate detailed instructions. For submersible applications of 150 feet or less, one-shot kits may be appropriately applied, especially to equipments that would not normally be needed to be submerged. For these instances, noncorrosive silicone sealant is recommended. The kit instructions should include the following information as a minimum:

- the surface preparation requirements.
- the locations to be sealed, amply illustrated to show the extent of seal necessary.
- cautions to avoid sealing or putting excessive sealant in critical areas.
- safety and handling precautions for the user.
- required/recommended cure times prior to submergence exposure.

One-shot kits should not be used as a general rule because repeated application and stripping of the sealant causes long-term damage to most package components,

especially connectors and shafted controls and some types of seals and gaskets otherwise important to the design. Also, one-shot kits often cannot maintain seals for designs that lack structural stiffness, especially at the design submergence depth, or for applications where the equipment is subject to much rubbing or bumping (causing the sealant to be peeled off).

5.2 Field change kit design. (for Class 3 requirements) Unless otherwise specified in the contract or order, field change kits should be designed to allow the retrofit to be accomplished by echelon 3 (field intermediate maintenance) technicians or by operator personnel. The field change kit should be considered (1) whenever the required modification cannot be easily reversed, (2) the modification does not negatively impact any of the design characteristics of the equipment, and (3) the change will not adversely impact the use of the equipment in nonsubmersible (general) applications. If the field change does not meet these criteria, the change may be designed for echelon 4 maintenance technicians and should include a special variant nomenclature change requested and assigned through normal procedures (MIL-STD-196) (for instance, AN/XYZ-123 (V1)). In general, field changes are guided by MIL-F-17655.

5.2.1 Housings. The considerations for field changes to housings are inclusive of those for retrofits (see 5.1.1). Additional alterations within the scope of field changes include the following:

- case modifications to provide glands for gasketing.
- conversion of equipments packaged in separable cases to unit packaging. This alternative is more expensive to accomplish and may combine separately nomenclatured items (such as the receiver-transmitter and power amplifier comprising a transceiver). However, unit submersibility may be substantially improved, and unit weight may be decreased. The modification must be designed carefully to prevent adversely impacting maintainability.
- case modifications to provide internal structural support for access covers.

5.2.2 Connectors. There are three primary concerns pertaining to connectors in a submersible application: corrosion of the electrical contacts, actuation or burnout of electrical functions, and seal through the connector. For nonoperating submersible applications, seal through the connector is the sole concern when no power is applied to the pins/sockets; it is assumed (and must be backed up by training and operator instructions) that the connector will be rinsed and dried prior to putting the equipment into service. For all other applications and when operator cleaning cannot be relied upon, the design concern is to keep the connector insert dry during submergence. The following design suggestions are provided:

- Provide suitable seals and gaskets between the connector and the housing it penetrates.
- Use hermetic environmental connectors. Hermetic series connectors have adequate seal specifications for submersible applications to depths in excess of 300 feet; however, hermetic seal requirements assume a maximum of one atmosphere differential pressure. Hermetic seal designs vary between suppliers and some may not have the structural integrity to withstand submergence pressures, especially in the larger connector shell sizes. Specification control

drawings will normally be necessary to maintain design control for submergence even though the connectors used are otherwise standard configurations.

- Provide connector caps with suitable gaskets. Most of the "dust caps" available for various series of connectors are capable of providing submergence protection to depths in excess of 300 feet; however, dust cap gasketing designs vary between suppliers and are not routinely tested for submergence pressures. A specification control drawing will normally be necessary to maintain design control.
- Connectors required to mate with terminal equipments and accessories may not have a configuration compatible with the submersible requirements. An adapter cable may provide the appropriate interface without compromising the connector requirements for submersibility.

5.2.3 Controls/Displays. Field change kit designs can take either of two substantially different approaches to control and display submersible packaging problems: a component-by-component approach or an integrated approach.

5.2.3.1 Individual component approach. In field change kits, this approach includes changing individual controls and displays to those having appropriate characteristics. This may also require design modifications to the "front" panel; if this is so, consider the integrated approach (5.2.3.2).

5.2.3.2 Integrated approach. The integrated approach replaces an entire panel of controls and displays with one using an integrated control/display technology. Implementation costs are relatively high, but reliability can be increased and the overall maintenance burden decreased. The field change implementation should include a connector interface between the control/display panel and the equipment electronics to allow the panel to be a replaceable maintenance item.

5.2.4 Technical documentation. Technical documentation for the field change should be prepared in accordance with MIL-F-17655 and as suggested below. Only documentation required by the contract or order is mandatory.

5.2.4.1 Design/procurement documentation. Design documentation for field change kits should generally include technical reports containing the analyses of the existing design to be changed, including (but not limited to) tradeoff cost analyses, weight impact analysis, seal design analysis, and reliability impact analysis. The procurement documentation should include the specifications and drawings necessary to procure and repro cure kits in small quantities from multiple sources.

5.2.4.2 Field change instructions. The field change kit instructions should provide directions for accomplishing the change and should contain a complete inventory of all items contained in the kit and items necessary for the modification not included (such as tools). The procedures should consist of detailed step-by-step instructions, amply illustrated by drawings and/or pictures, and written for a 7th grade reading level.

5.2.4.3 Operator and Maintenance Manual changes. Changes to the equipment technical manual(s) should include the following information elements:

- preventative maintenance instructions covering the inspection procedures for all seals.

- operator instructions peculiar to the kit or peculiar to the submersible requirement. For instance, modified instructions for changing batteries with precautions about the seals, and instructions for cleaning and rinsing connectors after exposure to salt water.
- replacement procedures for all seals and gaskets and other parts that may be peculiar to the kit.
- parts list information for all kit parts, seals, and materials. Parts that have been replaced by the kit should be deleted.
- illustrations of items substantially altered by the change should be changed to reflect the field-changed version. Differences between the original version and the changed version should be shown.
- directions for the disposition of parts replaced by the change.

5.3 New designs. (Classes 1 and 2). New designs shall be governed by the individual equipment specifications, the general equipment design specifications (MIL-E-16400 or MIL-E-4158, as appropriate and as referenced in the individual equipment specifications and contract or order), and by the requirements in this document as required by the contract or order. Requirements not made mandatory by the contract or order shall be considered in design as advisory information.

5.3.1 Design implementation. The detailed design shall be based upon the design analyses of paragraph 4.1.1 or 4.1.2, as specified. The design guidelines of paragraph 4.2 shall be followed as required by the contract or order.

5.3.2 Technical documentation. The technical information shall be provided in the form and according to the formats of the contract or order. Technical documentation for operator use shall include any special instructions for cleaning, rinsing, drying, or inspection after each submergence. Technical documentation for maintenance personnel shall include instructions for the inspection, maintenance, and replacement of all seals. Special quality assurance provisions for items screened for use to a design depth shall be documented by specification control drawing.

5.4 Reports. The results of the various design analyses required in paragraph 4.1 shall be documented in reports and provided as part of the design documentation package. The reports should be available in draft form at the preliminary design review (PDR), and should be updated and provided in final form at the critical design review (CDR). The reports shall contain the analytical assumptions, describe the analytical models, formulae, and tools (such as computer programs) in sufficient detail to (1) allow the interpretation of the results (commonly recognized models and tools may be cited by reference) and (2) present the results and conclusions describing the impact on the design and design tradeoffs, including costs, logistics support considerations, and human use criteria, as appropriate.

APPENDIX A

APPLICATION GUIDANCE FOR O-RINGS

10. GENERAL

10.1 Scope. This appendix provides information for the design of O-ring seals.

10.2 Application. O-rings are used to block the gap between two closely spaced surfaces, thus forming an effective environmental seal. The design guidance provided in this appendix is general, but it is intended for use in submersible applications.

10.3 Classification. O-ring service conditions may be classified as follows:

Type I Static—O-rings sealing without relative motion between the parts of the gland.

Type II Dynamic—O-rings sealing with relative motion between the parts of the gland. Examples include seals around control shafts and connectors subject to mating and unmating.

20. REFERENCES

20.1 Government documents. The following specifications of the issue listed in the current edition of the Department of Defense Index of Specifications and Standards form a part of this appendix to the extent specified herein.

MILITARY SPECIFICATIONS

MIL-R-3065 Rubber, Fabricated Products

MIL-G-5514 Gland Design; Packings, Hydraulic, General Requirements for

(Copies of the specifications and standards are stocked by the Naval Publications and Forms Center, Philadelphia, PA 19120 for DoD activities only. Suppliers should obtain copies from the procuring activity or as directed by the contracting officer.)

20.2 Other publications. The following documents form a part of this document to the extent specified herein.

ACCEPTED INDUSTRY STANDARDS

American Society for Testing and Materials (ASTM)

ASTM D2000-86 Rubber Products in Automotive Applications
(ASTM, 1916 Race Street, Philadelphia, PA 19103)

NONACCEPTED INDUSTRY STANDARDS

Society of Automotive Engineers (SAE)

AS-568A-74 Aerospace Size Standard for O-rings

AIR-786A-72 Elastomer Compatibility Considerations Relative to
O-Ring and Sealant Selection

(SAE, 400 Commonwealth Drive, Warrendale, PA 15096)

30. DEFINITIONS

30.1 O-ring. An O-ring is a torus of circular cross section made of an elastomeric material.

30.2 Gland. A gland is a groove or depression, usually with a rectangular cross section, and a facing surface used for the installation of an O-ring or gasket seal.

30.3 Stretch. Stretch is the elongation suffered by an O-ring elastomer beyond its design inside diameter.

30.4 Squeeze. Squeeze is the amount of linear deformation to the O-ring cross-section diameter required to fit into the gland.

40. GENERAL REQUIREMENTS

40.1 Design parameters. O-ring design parameters include dimensions and material selections. In general, O-ring designs should follow the requirements of MIL-R-3065, especially in the consideration of dimensional tolerances.

40.1.1 Dimensional considerations. Dimensional design considerations include the following:

- the size and shape of the parts to be sealed, such as the circumferential distance around the access through a case.
- the differential pressure to be maintained (0.445 psi per foot of specified submergence depth of seawater, to include operating safety margins).
- the gland gap to be sealed, including dimensional distortions caused by pressure acting on a large cover.
- motion requirements, if Type II.

40.1.2 Material considerations. Material design considerations include the following:

- motion requirements, including gland dimensional changes due to pressure and temperature changes and gland motions for Type II applications.
- fluids to be encountered from all equipment applications (not merely seawater submersibility).
- the temperature extremes to be encountered.
- the pressure differential to be sealed.

40.2 Design procedure.

40.2.1 Select elastomer material family. The general characteristics necessary to consider the design parameters are provided below for guidance in selecting an elastomer material. Refer to SAE AIR 786 and to table A-1 (at the end of this appendix) for fluid compatibility considerations.

Family Name	Service Conditions	Temp Limits (deg. C)	Hardness (Shore A)	Fluid Code
Nitrile (Buna N)	I, II	-55 to 125	40-90	B
Ethylene-propylene	I, II	-55 to 125	50-90	E
Neoprene (chloroprene)	II, (I)	-55 to 140	40-80	N
Fluorocarbon	I, II	-40 to 225	70-90	V
Silicone	I	-75 to 250	40-80	S
Fluorosilicone	I	-65 to 175	60-80	F

Family Name	Service Conditions	Temp Limits (deg. C)	Hardness (Shore A)	Fluid Code
Styrene-butadiene	II, (I)	-55 to 100	40-80	G
Polyacrylate	(II)	-18 to 175	70-90	L
Polyurethane	II	-55 to 100	60-90	U
Butyl	(I),(II)	-55 to 100	50-70	J
Polysulfide	{I}	-55 to 100	50-80	K
Chlorosulfonated polyethylene	{I}	-55 to 125	50-90	H
Epichlorohydrin	(I)	-55 to 125	50-90	Z

Note: Bracketed service conditions () offer good service; braced conditions { } offer marginal service. All others are highly recommended for the service condition(s) cited, Type I or Type II, but are not recommended for services omitted.

40.2.2 Select a standard size. Select standard-size O-rings as defined by the military-accepted standards for the O-ring family chosen (40.2.1). The most widely available standard sizes are found in AS-568. O-rings are defined dimensionally by their cross-section diameter and by their inside diameter (diameter for an assumed circle of the lesser circumference). Use the largest cross section that will fit in the available space; the following tradeoff factors should be considered:

- larger cross sections are less subject to damage during installation or from abrasion and less subject to roll or twist.
- larger cross sections are less affected by intermittent high temperature.
- stretch and squeeze tolerance conditions are usually more favorable with larger cross sections.

40.2.2.1 Stretch limits. Stretch should not exceed 5 percent of the nominal inside diameter of the O-ring. Excessive stretch reduces the cross section and causes accelerated deterioration in the presence of high temperature or exposure to marginal fluids. O-rings can be stretched during installation to clear shoulders and other obstacles. In general, this temporary stretch can be as high as 100 percent of the design inside diameter, but should be minimized to the least practical value.

40.2.2.2 Squeeze limits. The minimum recommended squeeze, regardless of cross section, is 0.006 inch. The maximum recommended squeeze is 35 percent of the cross-section diameter.

40.2.3 Determine maximum gap. The gap between the two gland surfaces must be sealed by the O-ring. In general, the smaller gap requires higher-cost machining of the gland. The gap is also affected by distortions in the gland caused by the distorting pressures on the component of which the gland is a part (a large access cover, for instance) and by restoring forces as a function of squeeze and O-ring hardness. The pressure being sealed acts on the O-ring, forcing it into the gland gap; if this pressure is too great for the gap size and O-ring hardness, the O-ring will be extruded into the gap, tearing the O-ring surface and causing a seal failure. In general, the following procedure can be used:

- Start initially with a standard O-ring hardness of 70 on the Shore A scale. This is a standard hardness available in almost every material family.
- Compute the worst-case tolerance stack-up for the static gland gap, exclusive of the O-ring. Include tolerances for parallelism between the

gland surfaces, surface flatness, etc., appropriate for the manufacturing techniques intended to be used.

- Add the gap increase due to warpage under pressure, thermal expansion/contraction, long-term wear, and any other factors that may be introduced by the design features.
- Compare the maximum expected gap to the maximum allowable gap for the applied pressure, adjusting the O-ring hardness as required to obtain the best tradeoff between manufacturing tolerances and seal performance as follows:

MAXIMUM ALLOWABLE GAP-INCHES

<u>Shore A Hardness</u>	90	80	70	60	50	40
<u>Specified Depth—feet</u>						
300 or less	0.033	0.030	0.028	0.024	0.019	0.015
300 to 600	0.029	0.025	0.021	0.017	0.011	0.006
600 to 1000	0.025	0.020	0.016	0.010	0.004	N/A
1000 to 1600	0.021	0.015	0.010	0.004	N/A	N/A
1600 to 3200	0.014	0.008	0.004	N/A	N/A	N/A
3200 to 5000	0.008	0.004	N/A	N/A	N/A	N/A
5000 to 7500	0.004	N/A				
over 7500, special designs required						

Greater gap-pressure capabilities can be achieved using a backup ring. Backup rings and special O-ring hardness specifications are special design cases not normally suitable for general service, so guidelines are not provided here. Consult MIL-G-5514 for design requirements outside of the ranges provided in this document.

40.2.4 Design gland. MIL-G-5514 provides general requirements for gland design; although written for hydraulic system design, these requirements are generally applicable to submersible applications. The gland dimensions take into account the design squeeze and the maximum gap. The designer should check the actual design dimensions chosen against these considerations to ensure the O-ring performance.

40.2.4.1 Specified gland dimensions. There are four important gland design features that must be specified:

- gland depth—the dimension from the bottom of a gland groove to the opposing gland surface.
- groove width—the width of the gland groove at the base or bottom surface.
- groove radius—the maximum radius of the edge between the groove walls and the groove base.
- groove surface finish—the maximum roughness that can be tolerated. The maximum surface roughness should be less than 32 microinches for Type I service and less than 16 microinches for Type II service.

The recommended dimensions for depth, width, and groove radius are given below. The recommended width is for an O-ring alone; conditions and use dimensions for the application of backup rings are provided in MIL-G-5514.

<u>O-ring cross section</u>	<u>Type I Service</u>			<u>Type II Service</u>		
	<u>depth</u>	<u>width</u>	<u>radius</u>	<u>depth</u>	<u>width</u>	<u>radius</u>
	(all suggested dimensions given in inches)					
	<u>0.048</u>	<u>0.090</u>		<u>0.055</u>	<u>0.090</u>	
0.070	0.054	0.100	0.015	0.057	0.100	0.015
	<u>0.077</u>	<u>0.140</u>		<u>0.088</u>	<u>0.140</u>	
0.103	0.083	0.150	0.020	0.090	0.150	0.020
	<u>0.109</u>	<u>0.180</u>		<u>0.120</u>	<u>0.180</u>	
0.139	0.115	0.190	0.025	0.124	0.190	0.025
	<u>0.168</u>	<u>0.280</u>		<u>0.184</u>	<u>0.280</u>	
0.210	0.176	0.290	0.035	0.188	0.290	0.035
	<u>0.222</u>	<u>0.370</u>		<u>0.234</u>	<u>0.370</u>	
0.275	0.232	0.380	0.050	0.240	0.380	0.050

40.2.4.2 Standard gland dimensions. In addition to the four specified dimensions, there are three design features that may be taken as standard dimensions:

- groove wall perpendicularity—the groove walls should not exceed 5 degrees from perpendicular with the groove base.
- groove break edge radius—the break edge radius at the interfacial or top edge of the groove should be 0.005 inch nominal.
- groove bend radius—the groove bend radius should not be less than 2 groove widths.

40.2.5 Design for installation. The effectiveness of a well-designed O-ring seal can be destroyed by improper or careless assembly. Much of the responsibility for proper assembly falls on the designer for providing a safe route for the O-ring on its way to the gland groove. The O-ring should not pass over sharp shoulders, keyways, or threads that could cause cuts or abrasion. Chamfers should be provided on cylinder bores and piston rods so the O-ring will not be pinched during installation. Tape or sheet metal thimbles can be used during assembly to shield threads or sharp corners over which the O-ring must pass. The equipment maintenance instructions should contain instructions for safe installation procedures in the field for field personnel using materials available in the field. The field instructions should also contain procedures to ensure cleanliness during installation, since chips, grit, and foreign matter can damage the O-ring. O-ring lubricants are often used to ease O-ring installation. While the use of lubricants is acceptable, their use is not recommended for the applications covered by this handbook.

40.2.6 Select material specifications. Having selected the O-ring material family (40.2.1), an appropriate compound must be specified from that family to provide the Shore A hardness determined for the maximum gap size. Specify the compound in accordance with MIL-R-3065. Standard compound specifications are identified and nomenclatured in ASTM D2000.

40.2.7 Document the design. Provide procurement documentation (standard military part number or compound (per ASTM D2000) and dimensions per specification control drawing) and technical manual elements for the installation, service life replacement, and inspection of each seal. All data shall be submitted in accordance with the standard requirements specified in the contract or order.

50. SPECIFIC REQUIREMENTS

50.1 Elastomer characteristics. Specific elastomeric characteristics are provided in tables A-1 and A-2. Table A-1 provides fluid compatibility information, and table A-2 provides elastomeric family characteristics.

Table A-1. Elastomer/Fluid Compatibilities.

Fluid	Code	Fluid	Code
Acetaldehyde	E	Animal Oil	B,V,F
Acetamide	B,E,N	Aqua Regia	E,F
Acetic Acid	E	Aroclor	V
Acetic Anhydride	N,E	Arsenic Acid	F,E
Acetone	E	Askarel	V,B,F
Acetophenone	E	Asphalt	V,K
Acetyl Acetone	E	Barium Chloride	B,E
Acetyl Chloride	V,E	Barium Hydroxide	B,E
Acetylene	E,B	Barium Sulfide	B,E
Acetylene Tetrabromide	V,E	Beer	B
Aerazine 50	E	Benzaldehyde	E
Air (below 300°F)	E,B	Benzene	V,F,K
Air (above 300°F)	S,V,F	Benzenesulfonic Acid	V,F,N
Alkazene	V,F,K	Benzine	V,F,K
Alum	B,E	Benzoic Acid	V,F,K
Aluminum Acetate	E,B	Benzochloride	V,F,E
Aluminum Bromide	B,E,N	Benzophenone	V,F,E
Aluminum Chloride	B,E,N	Benzyl Alcohol	V,F,E
Aluminum Fluoride	B,E,N	Benzyl Benzoate	V,F,E
Aluminum Nitrate	B,E,N	Benzyl Chloride	V,F
Aluminum Sulfate	B,E,N	Borax	B,E
Amines	E	Boric Acid	B,E
Ammonia (Anhydrous/liquid)	E,B	Boron Fluids (HEF)	V,F
Ammonium Carbonate	E,N	Brake Fluid (Auto)	E
Ammonium Chloride	B,E,N	Bromine	E,V,F
Ammonium Hydroxide	E,B	Bromine Water	E,F
Ammonium Nitrate	B,E	Bromobenzene	V,F
Ammonium Nitrite	B,E	Bunker Oil	B,V,F
Ammonium Persulfate	E	Butadiene	V,F,E
Ammonium Phosphate	B,E	Butane	B,V,K
Ammonium Sulfate	B,E	Butyl Acetate	E
Ammonium Sulfide	B,E	Butyl Acrylate	K
Amyl Acetate	E	Butyl Benzoate	E,V
Amyl Alcohol	E	Butyl Butyrate	E,V
Amyl Borate	B,N,K	Butyl Carbitol	E
Amyl Chloronaphthalene	V,K	Butylene	V,F,B
Amyl Chloride	V,F	Butyl Ether	K
Amyl Naphthalene	V,F	Butyl Oleate	V,E
Anderol L-774	B,V,F	Butyl Stearate	V,F,B
Aniline, Aniline Dyes	E	Butyraldehyde	E,K
Aniline Hydrochloride	E	Butyric Acid	V,E

Fluid codes are defined in paragraph 40.2.1 and are listed in order of recommended use.

Table A-1. Elastomer/Fluid Compatibilities (continued).

<u>Fluid</u>	<u>Code</u>	<u>Fluid</u>	<u>Code</u>
Calcium Acetate	E	Decalin	V,F,K
Calcium Bisulfate	B,N,V	Decane	B,V,F
Calcium Chloride	B,E,N	Deionized Water	E,B
Calcium Hydroxide	B,E,N	Denatured Alcohol	E,B
Calcium Hypochlorite	E,V	Detergents	E,B
Calcium Nitrate	B,E,N	Developing Fluids (Photo)	E,N
Calcium Sulfide	B,E,N	Diacetone	E
Carbitol	E,B	Diacetone Alcohol	E
Carbolic Acid	E,F	Dibenzyl Ether	K,E
Carbon Bisulfide	V,F	Dibenzyl Sebacate	V,E
Carbonic Acid	E,N	Dibromoethyl Benzene	V,F
Carbon Dioxide	B,E	Dibutylamine	E,N
Carbon Disulfide	V,F	Dibutyl Ether	K
Carbon Monoxide	B,E	Dibutyl Phthalate	E,K
Carbon Tetrachloride	V,F	Dibutyl Sebacate	E,K
Castor Oil	B	Dichlorobenzene	V,K
Cellosolve	E,K	Dichlorobutane	V,B
Cellosolve Acetate	E,K	Dichloro-Isopropyl Ether	K
Cellulubes	E,K	Dicyclohexylamine	B
China Wood Oil	B,	Diesel Oil	B,V,F
Chlorinated Solvents	V,F	Diester Synth. Lubricants	B,V,F
Chlorine	E,F	Diethylamine	E
Chlorine Dioxide	E	Diethyl Ether	K
Chloroacetic Acid	E	Diethylene Glycol	E,B
Chloroacetone	E	Diethyl Sebacate	V,E
Chlorobenzene	V,F	Diffuorodibromomethane	E
Chlorobromomethane	V,F,E	Diisobutylene	V,B,K
Chlorobutadiene	V,F,E	Diisooctyl Sebacate	V,E
Chlorododecane	V,F,E	Diisopropyl Ketone	E
Chloroform	V,F	Dimethyl Formamide	B,S,E
Chloronaphthalene	V,F	Dimethyl Phthalate	E,V
Chlorotoluene	V,F	Dioctyl Phthalate	E,V
Chlorox	E,F	Dioctyl Sebacate	V,E
Chlorophenol	V	Dioxane	E
Chromic Acid	E	Dioxolane	E
Cobalt Chloride	B,E	Dipentene	V,K,B
Coolanol	N,V,F	Diphenyl	V,F,K
Copper Acetate	E	Diphenyl Oxides	V,F
Copper Chloride	B,E	Dowtherm A or E	V,F
Copper Cyanide	B,E	Epichlorohydrin	E
Copper Sulfate	B,E	Ethanolamine	N,E,B
Creosote	B,V,F	Ethers	K
Cresols	F,V	Ethyl Acetate	E,K
Crude Oil	V,F	Ethyl Acetoacetate	E,K
Cutting Oil	B,V,F	Ethyl Acrylate	E,K
Cyclohexane	B,V,F	Ethyl Alcohol	E,B

Fluid codes are defined in paragraph 40.2.1 and are listed in order of recommended use.

Table A-1. Elastomer/Fluid Compatibilities (continued).

<u>Fluid</u>	<u>Code</u>	<u>Fluid</u>	<u>Code</u>
Ethyl Benzene	V,F, E	Fuel Oil	B,V,F
Ethyl Benzoate	V,F,K	Fumeric Acid	B,V,F
Ethyl Cellosolve	E,K	Furfural	E
Ethyl Cellulose	B,N,E	Furfuryl Alcohol	E
Ethyl Chloride	E,B,N	Gallic Acid	V,F,E
Ethyl Chlorocarbonate	V,F	Gasoline	B,V,F
Ethyl Chloroformate	V,F	Glycerine	B,E
Ethylene Chloride	V	Glycols	E,B
Ethylene Chlorohydrin	V,E	HEF-2	V
Ethylene Diamine	E,B	Helium	E
Ethylene Dibromide	V	Heptane	B,V,F
Ethylene Dichloride	V	Hexaldehyde	E,N
Ethylene Glycol	E,B	Hexane	B,V,F
Ethylene Oxide	E	Hexene	V,F,K
Ethylene Trichloride	V	Hexyl Alcohol	B,V,F
Ethyl Ether	K	Houghto-Safe 271, 620	B,E,V
Ethyl Formate	V,F,E	Houghto-Safe 1010, 1055, 1120	E,V
Ethyl Hexanol	B,E	Houghto-Safe 5040	B,V,F
Ethyl Mercaptan	V	Hydrolube	B,E,V
Ethyl Oxalate	V, K, F	Hydraulic Oil	B,V,F
Ethyl Pentachlorobenzene	V,F	Hydrazine	E
Ethyl Silicate	E,B	Hydrobromic Acid	E
Ferric Chloride	E,B	Hydrochloric Acid	E
Ferric Nitrate	E,B	Hydrocyanic Acid	E
Ferric Sulfate	E,B	Hydrofluoric Acid	E
Fluoboric Acid	E,N	Hydrofluosilicic Acid	E
Fluorolube	E,B	Hydrogen	E
Fluorochloroethylene		Hydrogen Peroxide	F,V,E
Food Oils	B	Hydrogen Sulfide	E,B
Formaldehyde	E,B	Hydroquinone	V,F
Formic Acid	E,N	Hypochlorous Acid	E
Freon 11	K,V,B	Iodine	V,E
Freon 12, 13, 13B1, 14	N,B,K	Isobutyl Alcohol	E,B
Freon 21	N	Isobutyl Butyrate	E,B
Freon 22	N,K,E	Isododecane	B,V,F
Freon 31, 32	N,E	Iso-Octane	B,V,F
Freon 112	K,B	Isophorone	E
Freon 113	N,B,K	Isopropyl Acetate	E,K
Freon 114	N,B,E	Isopropyl Alcohol	E,B
Freon 114B2	K,N	Isopropyl Chloride	V,F
Freon 115	B,N,E	Isopropyl Ether	B,K,N
Freon 142b, 152a, 218	N,B,E	JP-1 thru JP-6 Fuel	B,V,F
Freon C316	N,B,K	Kerosene	B,V,F
Freon C318	N,B,E	Lacquers	K,E
Freon BF	K,B,N	Lead Acetate	E
Freon MF	K,V,B	Lead Nitrate	E,B
Freon TF	N,B,E	Lead Sulfamate	N,E,V

Fluid codes are defined in paragraph 40.2.1 and are listed in order of recommended use.

Table A-1. Elastomer/Fluid Compatibilities (continued).

<u>Fluid</u>	<u>Code</u>	<u>Fluid</u>	<u>Code</u>
Liqroin	B,V,F	Nickel Chloride	E,B
Lime Bleach	B,E,V	Nickel Sulfate	E,B
Lime Sulfur	E,V	Nitric Acid (dilute)	E
Lindol	E,V	Nitrobenzene	V
Linoleic Acid	S,N	Nitroethane	N,E
Linseed Oil	B,V,F	Nitrogen	E,B
Liquid Oxygen	S,V	Nitromethane	K,E
Liquified Petr. Gas	B,V,K	Nitropropane	K,E
Lubricating Oils	B,V,F	Octadecane	B,V,F
Lye	E	Octane	B,V,K
Magnesium Chloride	E,B	Octyl Alcohol	E,V
Magnesium Hydroxide	E,V	Oleic Acid	B
Mg Sulfate, Sulfite	E,B	Oleum	E
Maleic Acid	V,K	Oronite 8200, 8515	N,B,V
Maleic Anhydride	V	Ortho-Dichlorobenzene	V,F
Malic Acid	B,V,F	OS-45	N,V,F
Mercuric Chloride	E,B	Oxalic Acid	E,V
Mercury	E,B	Oxygen (gaseous)	S,E
Mesityl Oxide	E,K	Ozone	E,N
Methyl Acetate	E,K	Paint Solvents	K
Methyl Acrylate	E,K	Palmitic Acid	B,V,F,K
Methylacrylic Acid	E,N	Para-Dichlorobenzene	V,F
Methyl Alcohol	E,N	Pentane	B,V
Methyl Bromide	V,F	Perchloric Acid	F,E
Methyl Cellosolve	E	Perchlorethylene	V,K,F
Methyl Chloride	V,F,K	Petrolatum	B,V,F
Methyl Cyclopentane	V,F,K	Petroleum Oils	B,V,F
Methylene Chloride	V,F	Phenol	F,V
Methylene Dichloride	V,F	Phenylbenzene	V,F,K
Methyl Ether	E,B	Phenylethyl Ether	K
Methyl Ethyl Ketone	E,K	Phenylhydrazine	V,E
Methyl Formate	N,E	Phorone	E
Methyl Isobutyl Ketone	E,K	Phosphate Esters, Alkyl	E
Methyl Isopropyl Ketone	E,K	Phosphate Esters, Aryl	V,E
Methyl Methacrylate	K	Phosphoric Acid (45%)	E
Methyl Oleate	V,E	Phosphorous Trichloride	E,V
Methyl Salicylate	E	Picric Acid	E
Monomethylaniline	V	Pinene	V,F,B
Monobromobenzene	V,K	Plating Solutions	E
Monochlorobenzene	V,F	Pneumatic Service	B,E,N
Monoethanolamine	E	Polyvinyl Acetate	E
Monovinyl Acetylene	E,B	Potassium Acetate	E
Naphtha	V,B,F	Potassium Chloride	E,B
Naphthalene	V,F,K	Potassium Cyanide	E,B
Natural Gas	B,V,E	Potassium Dichromate	E,B
Neatsfoot Oil	B,V,F	Potassium Hydroxide	E
Nickel Acetate	E,B	Potassium Nitrate	E,B

Fluid codes are defined in paragraph 40.2.1 and are listed in order of recommended use.

Table A-1. Elastomer/Fluid Compatibilities (continued).

<u>Fluid</u>	<u>Code</u>	<u>Fluid</u>	<u>Code</u>
Potassium Sulfate	E,B	Sodium Phosphate	E,B
Potassium Sulfite	E,B	Sodium Silicate	E,B
Prestone (antifreeze)	E,B	Sodium Sulfate	E,B
Propane	B,V	Sodium Sulfide	E,B
Propyl Acetate	E,K	Sodium Sulfite	E,B
Propyl Acetone	E,K	Sodium Thiosulfate	E,B
Propyl Alcohol	E	Stannic Chloride	E,B
Propyl Nitrate	E	Stannous Chloride	E,B
Propylene	V,F,K	Steam	E,B
Propylene Oxide	E	Stearic Acid	B,E
Pyranol	B,V,F	Stoddard Solvent	B,V,F
Pydraul 150	E,V	Styrene	V,F
Pydraul A-200	V,F,K	Sulfur	N,E
Pydraul A C	E,V	Sulfur Chloride	V,F
Pydraul F-9	E,V	Sulfur Dioxide	E,V
Pydraul 625	E,V	Sulfur Hexafluoride	N,E
Pyridine Oil	E	Sulfur Free Compound	N
Pyrolube	V,E	Sulfur Trioxide	V,E
Red Oil (MIL-H-5606)	B,V,F	Sulfuric Acid	E
RJ-1, RP-1	B,V,F	Sulfurous Acid	E
Rapeseed Oil	E,V	Tannic Acid	E,B
Sai Ammoniac	E,B	Tar	V,B
Salicylic Acid	E,V	Tartaric Acid	B,V,F
Salt Water	E,B	Tertiary Butyl Alcohol	V,B,E
Sewage	E,B	Tertiary Butyl Catechol	V,E
Silicate Esters	N,V,F	Tertiary Butyl Mercaptan	V
Silicone Greases	E,B	Tetrabromoethane	V,F
Silicone Oils	E,B	Tetrachloroethane	V,F
Silver Cyanide	E,B	Tetrachloroethylene	V,F
Silver Nitrate	E,B	Tetraethyl Lead	V,F,B
Skydrol	E	Tetrahydrofuran	E,K
Soap Solutions	E,B	Tetralin	V,F
Sodium Acetate	E,B	Titanium Tetrachloride	V,F
Sodium Bicarbonate	E,B	Toluene (Toluol)	V,F
Sodium Borate	E,B	Transformer Oil	B,V,F
Sodium Bisulfate	E,B	Triacetin	E
Sodium Bisulfite	E,B	Tributoxyethyl Phosphate	E,V
Sodium Carbonate	E,B	Tributyl Mercaptan	V,E
Sodium Chloride	E,B	Tributyl Phosphate	E,K
Sodium Cyanide	E,B	Trichloroethane	V,F
Sodium Dichromate	E,B	Trichloroacetic Acid	E,B
Sodium Hydroxide	E,B	Trichloroethylene	V,F
Sodium Hypochlorite	E,N	Tricresyl Phosphate	E,V
Sodium Metaphosphate	E,B	Triethanolamine	E
Sodium Nitrate	E,B	Trinitrotoluene	V,N
Sodium Perborate	E,B	Trioctyl Phosphate	E
Sodium Peroxide	E,B	Trisodium Phosphate	E,B

Fluid codes are defined in paragraph 40.2.1 and are listed in order of recommended use.

Table A-1. Elastomer/Fluid Compatibilities (continued).

<u>Fluid</u>	<u>Code</u>
Tung Oil	B,V,F
Turbine Oil	V,B
Turpentine	B,V,F
Unsym.Dimethyl Hydrazine	E
Varnish	V,K,F
Versilube F-50	E,B
Xylene (Xylol)	V,F,B
Xylidenes	B,E
Zinc Acetate	E,B
Zinc Chloride	E,B
Zinc Sulfate	E,B
See Table A-2 for additional general characteristics.	
Chemical Agents	V,E,F
Decontamination Agents	E (B,F,S,V are also serviceable)

Fluid codes are defined in paragraph 40.2.1 and are listed in order of recommended use.

Table A-2. Elastomer Family Usage Characteristics.

NITRILE (Buna N)

Compounds of this family are "standard" for most O-ring service. Nitrile materials perform satisfactorily in a wide variety of fluids, including alkaline and salt solutions, petroleum, lubricating, and hydraulic oils, gasoline, alcohol, and water. Nitriles can be especially formulated to contain lubricants (graphite or molybdenum disulfide) or for long-term contact with polycarbonate plastic (such as display windows). Some formulations are especially resistant to biological agents.

ETHYLENE-PROPYLENE

This family has excellent resistance to water, steam, acid, ketones, phosphate esters, automotive brake fluids, and ozone. Compounds of this family are not recommended for petroleum oils. Ethylene-Propylene remains serviceable after 500 MRoentgens gamma radiation cumulative dosage. Some formulations are especially resistant to biological agents.

NEOPRENE (Chloroprene)

Good ozone and weather resistance plus excellent resistance to refrigeration fluids are characteristics of this family. Neoprenes are generally unsatisfactory for use with aromatic hydrocarbons, chlorinated solvents, and ketones. Neoprenes can be impregnated with lubricants (graphite or molybdenum disulfide) for high-friction dynamic applications.

FLUOROCARBON

This family has inherent compatibility with a wide range of chemicals and provides high temperature stability. Fluorocarbons are suitable for use with petroleum oils, silicone greases, and halogenated hydrocarbons, but should not be used with ketones or anhydrous ammonia.

SILICONE

Silicones are capable of great extremes in temperature (275°C sustained high temperature, remains flexible at -100°C), but they are relatively weak in physical strength and abrasion resistance (limited to static service).

FLUROSILICONE

This family combines good extreme-temperature performance with resistance to petroleum oils and hydrocarbon fuels.

STYRENE-BUTADIENE

This family works well with water, alcohol, silicone oils, and automotive brake fluids.

POLYACRYLATE

Polyacrylates have outstanding resistance to petroleum fuels and oils. They are also resistant to sunlight and ozone. The family is widely used in automotive automatic transmissions and power-steering mechanisms.

Table A-2. Elastomer Family Usage Characteristics (Continued).

POLYURETHANE

Polyurethanes exhibit excellent tensile strength and very good abrasion resistance. They are resistant to petroleum oils, hydrocarbon fuels, oxygen, and ozone, but they are not recommended for acids, ketones, chlorinated hydrocarbons, and water.

BUTYL

Butyls are all-petroleum products with excellent resistance to gas permeation. They are used in vacuum applications and are also used with phosphate esters. Butyls are also recommended for ketones and silicone fluids, but not for petroleum oils or fuels.

POLYSULFIDE

This family has outstanding resistance to oils, greases, and solvents, and polysulfides remain quite flexible at low temperatures. Their heat resistance and mechanical strength are not outstanding. They have good resistance to oxygen, ozone, and weather.

CHLOROSULFONATED POLYETHYLENE

This family has excellent resistance to ozone, oxidents, heat, and weathering. However, resistance to petroleum-base fluids is moderate, and mechanical properties are generally lower than other elastomers.

EPICHLOROHYDRIN

This family has excellent resistance to hydrocarbon fuels and oils, vegetable oils, and ozone. The high temperature resistance of epichlorohydrins is also good for limited-term exposure.

APPENDIX B

INTEGRATED CONTROL/DISPLAY TECHNOLOGIES

10. GENERAL

10.1 Scope. This appendix provides information and tradeoff criteria for using integrated control/display technologies, especially in submersible applications.

10.2 Application. The guidance and tradeoff criteria in this appendix are advisory. The information is provided to suggest design alternatives that are particularly appropriate to submersible applications, but that apply broadly to general applications. The intent of this information is to enable equipments designed primarily for general applications to have a significant submersible capability with a relatively insignificant design/cost impact.

20. REFERENCES None.

30. DEFINITIONS

30.1 Embedded component technology. Embedded component technology is a packaging approach that encapsulates, laminates, or otherwise embeds individual components into the single package.

30.2 Integrated controls. Integrated controls refer to a design and manufacturing concept in which all control elements are produced as a single component (as in membrane switch technologies).

40. GENERAL REQUIREMENTS

40.1 Integrated control/display technology. Integrated control/display technology combines separate, but compatible, control and display technologies into an integrated package. The result is a subassembly that contains all of the control and display functions for an equipment.

40.1.1 Design concepts. Integrated control/display panels can range from rather standard designs to exotic implementations. The most common approaches use separate control and display components mounted to a common panel as in the RT-1209/PRC-104. These common designs offer improved producibility and maintainability over nonintegrated panels, but their suitability for submersible applications may be limited by the individual components used. The most exotic concepts are found in aircraft and may employ projection displays and controls activated by eye movements. These exotic concepts generally can improve the human interface design substantially, but they are generally very costly and are not suitable for submersible applications. The integrated technology best suited for submersible applications employs embedded components. Embedding the control and display components provides the most environmentally sealed design. Embedded designs allow integrated shielding for EMI and TEMPEST as well as protection from submergence, dust, and fluids. The higher design and nonrecurring engineering costs of embedded approaches are normally offset by the following: (1) lower production costs, (2) higher production yields, and (3) very low life-cycle costs when amortized over production runs of as few as 30 units and a projected service life exceeding 5 years. Embedded technologies sacrifice maintainability for substantial improvements in overall reliability (sometimes reducing control/display panel failure rates by an order of magnitude or more).

40.1.2 Maintenance concepts. Usually, the control/display subassembly is a separable maintenance item for the equipment of which it is a part. When it is a separable maintenance item, it is usually replaceable at the field maintenance level (echelon 3) and is serviced at a depot. Many control and display technologies are not repairable; however, integrated panels may be designed so that they allow individual replacement of the display or control elements. The maintenance design for integrated panels should be determined by a level of repair analysis.

40.2 Display technologies.

40.2.1 Class 1 applications. Displays suitable for submerged use have two unique requirements beyond the normal information display requirements:

- ability to withstand submergence pressures.
- ability to be used underwater (under adverse lighting conditions).

The display technologies cited in the subparagraphs below are generally suitable for integrated panels for Class 1 applications. These technologies are each capable of producing sufficient luminance for submersible use. None of these technologies is inherently capable of withstanding submergence pressures; the technologies must be protected by the display panel packaging. The technologies cited in subparagraphs 40.2.1.1 through 40.2.1.3 are preferred for integrated control/display panels.

40.2.1.1 Electroluminescent (EL) displays. EL displays are compatible with all control technologies. EL displays are available in multiple colors, but more than one color in a display panel may significantly increase costs. At luminance levels suitable for direct sunlight use, EL displays consume significant amounts of current, but typically less than comparable incandescent displays. Most EL implementations require a shade/hood to shield direct sunlight, allowing lower design currents. Initial design costs tend to be higher than other technologies, but production costs are low as part of an integrated panel. EL display reliability is very high. When used in an embedded panel design, EL displays can function to submergence depths of several thousand feet.

40.2.1.2 Light emitting diode (LED) and vacuum fluorescent displays. LED displays are inexpensive to design and produce. They are not well-adapted to graphic displays. (Although the AN/PSC-2 Digital Communications Terminal uses an array of 19000 LEDs for graphics and alphanumeric displays, such an implementation is expensive.) LED technologies are extremely rugged and reliable, and they are compatible with all control technologies. LED luminance is usually poor for direct sunlight applications, but very adequate for shaded uses. LEDs use moderate drive currents. Most hermetic LEDs can function to a submergence depth of 300 feet without extraordinary protection; nonhermetic displays are not recommended for submersible applications. Vacuum fluorescent technology is very similar to LED technology in application except that it is less readily available in ruggedized forms; vacuum fluorescent displays are similar in display capability to LCDs.

40.2.1.3 Back-lit liquid crystal displays (LCD). LCD technologies are characterized by low costs, high reliability, and general compatibility with control technologies. They are becoming a favored implementation of diverse displays required by the typical equipments encountered in infantry applications. They are excellent for use in direct sunlight. However, LCDs have no built-in luminance and are susceptible to

temperature extremes. By providing backlighting, LCDs become usable in low light conditions. Although LCDs are very low power devices (a prime design consideration in selecting this technology), backlighting and thermal controls (to extend low temperature operation) consume power that may make the display assembly moderately high in power consumption under some operating conditions. An EL backlight is often used with LCDs when power consumption must be minimized. The color of the backlight or filtered front-lighting provides the perception of color, so color differentiation is limited. LCD technology is very flexible and adaptable to intermixed text and graphics; properly implemented, the technology can contribute substantially to equipment human-factors design. The LCD graphics resolution is only moderate: higher than LED or EL capabilities but lower than CRT or plasma designs. LCD displays require additional structural protection for submersible applications because submergence pressures can distort the liquid crystal, causing nonfunctioning display areas. A high-intensity backlight can be used to create a projection display of moderate resolution.

40.2.1.4 Cathode ray tube (CRT) displays. CRT displays offer considerable design flexibility at moderate cost; many design configurations and color capabilities are available. Ruggedized versions are moderately reliable, but CRTs are generally susceptible to shock, vibration, thermal shock, and high temperatures. Low-power versions are available, but high drive voltages are still required. CRT's are usable under a variety of lighting conditions. CRTs produce EMI and heat, so they must be incorporated with care. The support electronics and packaging requirements for CRTs make them generally unsuitable for integrated control/display designs; however, miniaturized "flat" CRT technology does integrate especially well with transparent membrane switch or interrupted beam control technologies. This miniaturized technology can be used in projection display applications, but the power consumption of the display system is high. CRT technology is capable of extremely high resolution graphics. CRT displays should be isolated from direct exposure to submergence.

40.2.1.5 Plasma and incandescent displays. Plasma and incandescent display technologies are radically different in implementation, but similar in application characteristics in state-of-the-art designs. Plasma displays are rugged, reliable, and relatively costly, but they are capable of high resolution graphics and great design flexibility. The simple plasma numeric indicator is inexpensive and limited in display capability. Incandescent displays range in complexity from the simple indicator bulb to alphanumeric to moderately high-resolution graphics. Incandescent reliability decreases as complexity increases, but costs are moderately low. Plasma and incandescent displays consume similar amounts of power, except that plasma displays require high voltage while incandescent displays are current driven. Both technologies are susceptible to high temperature, and both technologies produce excess heat that may affect colocated electronics. Both technologies are rugged, but reliability is decreased markedly in high shock and vibration environments. The simple devices can be integrated well with most control technologies, but the complex graphic devices only integrate well with transparent membrane or interrupted beam control technologies. Some plasma technologies are susceptible to high temperature "wash-out" that renders them unusable. Plasma and incandescent displays should be isolated from direct submergence.

40.2.2 Class 2 and 3 applications. Displays for Class 2 or 3 applications include all those cited in 40.2.1 plus those cited in the subparagraphs below.

40.2.2.1 Liquid crystal displays (LCD). Same as 40.2.1.3, except not useful in low-light conditions.

40.2.2.2 Mechanical numeric displays. Mechanical displays are directly activated by the controls to which they are connected (mechanically, electrically, or electro-mechanically). They tend to be highly reliable if they are environmentally sealed; otherwise, wear of the linkage to the control can cause ambiguous displays after a few thousand hours of operational use. These displays are useful when low cost is a primary issue and when there are very few display elements; costs rise exponentially with complexity for both design and production with this technology. Power requirements are low or nonexistent. Separate illumination is required for low-light applications. Many such displays can be submerged to great depths; however, the submergence depth may be limited by associated seals.

40.2.3 Auditory displays. Auditory displays include speakers or earphones and buzzers or alarms. For most equipments in submersible applications, audio is provided through a handset or headset accessory. In general, speakers, earphones, and buzzers/alarms for submersible use are custom designs and may not be suitable for general use. When a speaker or alarm is required for general use on an equipment that must be submersible, the audio display can be mounted inside of a membrane seal that is part of an integrated control/display panel. The membrane seal may have a structural backing as part of the panel. The presence of the membrane seal will alter the acoustic characteristics of a speaker; this must be compensated for in the driving circuitry to maintain specified intelligibility characteristics. Standard audio displays will not function normally while submerged even behind a membrane because of inefficient coupling of the sound into the water. When audio displays are required to function while submerged, a separate, custom-designed device should be used.

40.3 Control technologies.

40.3.1 Class 1 applications. Controls for Class 1 applications must function normally while submerged. Seals must not break down when the control is manipulated while at the specified depth, and the submergence pressure must not prevent the use of the control nor cause faulty control actuations. The control technologies cited in the subparagraphs below are generally suitable for Class 1 applications.

40.3.1.1 Magnetic technologies. Magnetic technologies include reed switches, disk switches, and Hall-effect switches. In all cases, the switch is activated by a magnetic field, which is provided by a permanent magnet moved by operator action. Magnetic technologies allow the activator mechanism (magnet and mounting) to be exposed directly to the environment while the switch is packaged behind the environmental seal of the control panel. The actuator must be designed carefully since it is exposed to the submersible environment. Magnetic technologies must be shielded from stray magnetic fields such as from electric motors and those associated with CRTs. The switches are momentary action except as noted below.

40.3.1.1.1 Reed switches. Reed switches consist of contacts that touch each other to close a circuit in the presence of a magnetic field. The contacts are typically sealed in a glass tube. The activating magnet can be provided in a variety of mechanisms including pushbutton, rocker, and slide configurations. The rocker and slide mechanisms can contain mechanical detents that can provide two-circuit or alternate-action

switch configurations when used with a pair of reed assemblies. Reed switches are generally physically large (1 inch by 0.125 inch in diameter) and require actuator travel on the order of 0.25 inch to assure reliable operation. Costs range from \$10 to \$45 per position.

40.3.1.1.2 Disk switches. Disk switches use a magnetically operated disk and a stationary contact; otherwise, they are similar to reed switches. Disk switches are available only in pushbutton forms. Disk switch technology is compatible with mounting in an array. Costs and reliabilities are similar to reed switches.

40.3.1.1.3 Hall-effect switches. The Hall-effect is an electronic analog to the mechanical effects employed in reed switches. Hall-effect switches require somewhat less travel than reed or disk switches and can be made physically smaller; however, some support electronics are required to interpret the switch action. Like the reed switch, the Hall-effect actuator can be packaged as a pushbutton, rocker, or slide; and the rocker and slide configurations can be made alternate action rather than momentary action. Hall-effect switches are somewhat more reliable than reed switches. Individual Hall-effect switches are available in unit quantities at costs comparable to reed switches, but the Hall-effect technology lends itself to switch arrays and integrated panel technologies, significantly decreasing unit switch costs for large numbers of switch positions.

40.3.1.2 Interrupted light beam technologies. Interrupted light beam technology uses a light source (usually an infrared LED) to illuminate a photodetector; when the beam is interrupted, circuitry detects the change in the photodetector and interprets the desired switch action. A matrix of beams may be formed across a display face to form complex interpreted control positions. Since the display can be used to show the current control function, each control position in the matrix can serve multiple variable functions. The operator points to the display indication and, using a finger, interrupts the beam over the display. The design cost of an array is usually rather high, especially for software/firmware to interpret the controls, but production costs are relatively low. The technology exhibits high reliabilities and great flexibility for incorporating future design changes. Individual interrupted beam switches can be made for about the cost of a reed switch and will occupy about the same amount of panel space (0.75 to 1 inch square). A smaller switch (0.37 inch square) can be made by interrupting the beam with a barrier attached to an actuator; this switch form can be cost-competitive with other switch forms while achieving short actuation travel distances and different switch forms (push, rocker, rotary, or slide). The technology has the drawbacks of requiring a continuous light source and extensive interpretive logic. Another drawback is that the technology is not supported by a large base of standard commercial products. Designs employing this technology must consider the effect of an LED failure and of dirt/dust contamination. Since the submersibility of the technology depends on the environmental seal of the LED and photodetector, the technology is limited to 300 to 400 feet operating depths with standard designs.

40.3.1.3 Differential pressure technologies. There are two basic forms of differential pressure technology. One form uses an incompressible fluid to provide restoring force to a pushbutton (usually a membrane switch); actuation of the button forces the fluid into a reservoir that balances the pressure due to submergence. The second form uses the piezoelectric effect to "measure" the pressure and circuitry to recognize rapid changes in output characteristics of a control actuation (and to distinguish changes

due to diving or pressure waves). Both forms are inherently momentary contact switch functions and require circuitry to create other control functions. Both forms involve custom designs that can be costly, but the production cost is primarily a function of the control electronics. If care is taken in design to customize for the entire range of environmental extremes, extremely high reliabilities can be achieved; the control electronics tend to drive the actual reliability.

40.3.1.4 Mechanical detent technologies. Virtually all forms of standard switches and other control types are available with environmental seals that can be specified to perform at submergence depths of several hundred feet. Design and production costs are typically low, but part qualification costs can be quite high. The overall control system reliability tends to depend upon good maintenance of the environmental seals; this may be difficult in some operational applications.

40.3.2 Class 2 and 3 applications. Controls suitable for Class 2 or 3 applications include all those cited in 40.3.1 plus those cited in the subparagraphs below.

40.3.2.1 Membrane switch technologies. There are a host of membrane switch technologies. Only those technologies that are environmentally sealed should be considered for submersible applications. Membrane switches are inherently momentary contact devices, so they require decoding circuitry. The wide variety of implementations are compatible with virtually any form of display. Typically an entire panel of membrane switches can be produced at the cost and reliability of two discrete switches. Furthermore, the integrated control panel design can include shielding and environmental resistance to fluids to a degree not achieved in other control technologies. Some membrane technologies are susceptible to overpressure damage. Examples of overpressure damage include the delamination of intraswitch layers, the bonding of contact surfaces, the inversion of tactile feedback domes, and the permanent distortion of the environmental membrane. All of these damage modes can be avoided to pressures equivalent to at least 600 feet by suitably selecting materials, switch contact geometries, and assembly processes. Depth pressures will activate membrane switches (except for the special case covered in subparagraph 40.3.1.3). The designer should ensure that no damage can occur from activations caused by depth, taking into account that all switch positions will vary slightly in the pressure at which they activate due to tolerances of the membrane.

40.3.2.2 Boot and seal technologies. Boots are flexible environmental barriers that are available for most types of controls. Transparent boots are available for control/display combinations such as illuminated pushbutton switches. Seals are available for the standard types of controls that have rotating shafts. Boots and seals can generally be employed to depths of 300 to 400 feet without special design considerations. Special designs can extend their performance to several thousand feet. Although boots and seals are inexpensive and easy to implement or retrofit, their use should consider their susceptibility to damage by puncture or tearing in the operational environment.

40.3.3 New control technologies. The technologies described in the following subparagraphs are emerging technologies. They are described as technologies that may have application to future submersible equipments.

40.3.3.1 Light pens and magnetoresonant wands. Light pens and magnetoresonant wands are pointing devices that can be integrated with a display to provide control

functions. The technologies involved are quite different, but the application considerations are similar. In both cases, the pen or wand is a sensor that is synchronized to a graphics display scan; a pushbutton on the wand allows the system to recognize what part of the display is being addressed. System firmware or software interprets the required control function. Light pens are used with CRT displays; magneto-resonant wands are used with plasma displays or with a control grid over a liquid crystal display. Both technologies allow extensive controls to be integrated into a very small space while maintaining good human-factors interface capabilities. In submersible applications, the design of the selection button on the pen or wand and the encapsulation/seal of the subassembly will be the most unique design requirements.

40.3.3.2 Fiber-optic switches. Fiber-optic switches consist of a light source fiber and one or more sensor fibers that can be coupled by either a movable fiber jumper or by a reflector built into the switch actuator. The fibers are usually encapsulated into the control panel while the switch actuator can be outside the environmental seal boundary. Fiber-optic switches are capable of performing toggle, slide, and rotary switch functions. The small geometries of the fibers allow a large number of switch positions to exist under a single actuator, so a potentiometer function can be simulated in a rotary switch. Likewise, multipole switch functions that are beyond practical implementation in mechanical switches can be implemented with the fiber-optic technology. The source fibers are normally routed to a single light source, so the power requirements can be minimized. The sensor fibers connect to individual sensors that may be an integrated part of the interpretive control circuitry.

40.3.3.3 Light wand. The light wand contains a light source that forms a low intensity, narrow beam. Sensors are encapsulated into the control panel. The light source is selected to avoid extraneous activation from ambient light sources. The operator points the wand at the desired control location and pushes a selection button to activate the function. In one implementation of this technology, the light source is in the control panel and is conducted to the light wand by fiber-optic bundle; the activation button is a mechanical gate that blocks the source except during the selection.

40.3.4 Control implementation options. Control functions may be implemented in various ways. The common control implementations include potentiometers and toggle, rotary, slide, and pushbutton switches. Alternatives to each are discussed in the following subparagraphs.

40.3.4.1 Potentiometers. Potentiometers are used to provide a smooth analog variance in a control function (such as a volume control). The potentiometer provides the advantage that the control knob can provide a pointer indication of the relative setting. Potentiometers are inexpensive, but they are difficult to seal and are high failure rate items in many submersible applications. Alternatives to potentiometers (and other variable analog controls) include stepped control functions implemented with rotary switches or momentary switches with stepping circuitry. Rotary switches provide greater reliability at about the same cost; they are appropriate when there are too few controls to justify highly integrated switch technologies. Momentary switches provide much higher reliability at significantly lower cost if implemented as part of an integrated control/display panel. (Note: It may be necessary to provide a visual indication of the function setting.)

40.3.4.2 Toggle switches. Toggle switches offer compact switch functions that are relatively easy to environmentally seal. The toggle switch provides some visual

indication of the switch position, although not as good an indication as rotary switches with long control knobs. Toggles can be obtained in a variety of forms that mix momentary and lock-in states. The high physical profile of the toggle handle makes it susceptible to inadvertent operation and to damage of the seal. Rotary switches and pushbutton switches are the primary alternatives. Rotary switches consume more control panel space and generally cost more (nominally) and have somewhat higher failure rates. Pushbutton switches generally require additional circuitry to implement the functions easily obtained in toggle switches. Only highly integrated forms of momentary switch technology can achieve the functions of the toggle switch at comparable costs and reliability.

40.3.4.3 Rotary switches. Rotary switches are available in various forms and environmental seal capabilities. Those forms available with a seal suitable for submersible applications do not include the more complex control functions. Rotary switches are especially well adapted to "mode selection" functions. Multiple pushbuttons are usually needed to replace a rotary switch, usually to achieve better human interface characteristics. Highly integrated momentary switch technology can provide the control/display feature of the rotary switch at a comparable or lower cost and at higher reliability.

40.3.4.4 Slide switches. Slide switches are inexpensive and can provide multiple throw positions with some operator indication; however, they are highly unreliable in submersible service. All other switch technologies are preferred over slide switches for submersible applications. Toggle and rotary switches are preferred for simple control panels in small quantities. Integrated momentary controls are preferred for higher quantities and for high reliability performance.

40.3.4.5 Pushbutton switches. Pushbutton switches are available in alternate action and momentary action and with or without an integral display. Momentary action switches are slightly less complex and more reliable. Pushbuttons are normally sealed by boots that are relatively easy to damage in field service. However, the variety of integrated momentary switch technologies offers an inherent environmental seal. An integrated control panel implementing any number of control functions and meeting shock, vibration, EMI, and submergence criteria can be produced for about the cost of two discrete pushbuttons that meet the same criteria. In addition, the integrated control panel will usually have a lower failure rate than the discrete switches, even with the added circuitry requirements. Integrated switch technology becomes the most economic choice (considering design and production costs) when the product of the number of switch positions per panel and the number of panels to be produced exceeds about 500.

40.4 Secondary controls. The control technologies suitable for integrated control/display panels are inherently small signal technologies. Secondary controls are devices located within the equipment that are activated by these primary controls in order to switch high voltages, high currents, radio frequencies, or other special application signals. Devices suitable for secondary control applications include various types of relays, and various solid-state switches, stepping switches, and logic-controlled switches. The only special concern for using these devices in submersible applications occurs if they are driven by controls in a separable enclosure. In this special circumstance, the designer should not only provide a design that suitably seals the connector pair between the enclosure, but an analysis should also be included

describing the consequences of that seal failure on the secondary controls and the controlled equipment elements.

50. SPECIFIC REQUIREMENTS None.

APPENDIX C

ALTERNATIVE PACKAGING CONCEPTS

10. GENERAL

10.1 Scope. This appendix provides information on packaging concepts that are suitable for submersible applications but that have design characteristics that may not be suitable for general applications.

10.2 Application. This appendix is provided for information to designers of submersible equipment. It may provide information useful in making design tradeoffs, but it does not contain any expressed or implied requirements. The advantages and disadvantages listed for each concept may or may not apply to the unique requirements of a particular equipment.

20. REFERENCES None.

30. DEFINITIONS None.

40. GENERAL REQUIREMENTS

40.1 Free-flooding packaging. In free-flooding packaging, the enclosure provides structural protection against impacts and the required degree of electromagnetic shielding but admits the outside environment. Therefore, protection against salt water is provided by conformal coatings and sealings internal to the enclosure.

40.1.1 Advantages.

- light weight.
- ease of cooling internal components.
- ability to design for fast internal access of major subassemblies.

40.1.2 Disadvantages.

- Individual components must be able to withstand submergence pressures. (This has been found to be true for virtually all hermetic components to depths of about 400 feet; however, it must be verified for each component type during design.)
- Insulation requirements increase.
- Potential for corrosion increases.
- Maintainability at the component level may be substantially decreased by the need to clean away conformal coatings.
- Sealing requirements may not be adequately restored after maintenance.

40.2 Filled packaging. In filled packaging, the enclosure is filled up with an encapsulant or an incompressible fluid, such as an oil or grease. The package fill must be an electrical insulator. The package fill also excludes salt water from sensitive circuitry and adds structural integrity to an otherwise lightweight enclosure.

40.2.1 Advantages.

- Structural integrity increases.
- Thermal performance is better, if the fill is thermally conductive (as is heat sink compound).

40.2.2 Disadvantages.

- Each component must be capable of withstanding submergence pressures transmitted by the fill.
- Thermal performance is worse, if the fill is not thermally conductive.
- Maintainability is reduced substantially by the need to clean away the fill before corrective maintenance is performed.
- The resulting package is heavier, often doubling the enclosure weight.

40.3 Cylindrical or spherical packaging. Cylindrical and spherical shapes offer substantially more structural integrity than the traditional rectangular prism. This form of packaging is commonly used in equipments designed for exclusive submersible applications. This is a form of unit packaging (see 40.4) plus geometry.

40.3.1 Advantages.

- a stronger, lighter enclosure.
- fewer seals to design and maintain.

40.3.2 Disadvantages.

- more expensive to design and produce.
- reduced thermal dissipation due to reduced surface-to-volume ratio.

40.4 Unit packaging. Unit packaging employs a single case and a single case access without separable enclosure components.

40.4.1 Advantages.

- fewer seals to design and maintain.
- greater structural integrity at lower weight.

40.4.2 Disadvantages.

- less accessibility for maintenance and for battery changes.

50. SPECIFIC REQUIREMENTS None.

APPENDIX D TAILORING GUIDANCE

10. GENERAL

10.1 Scope. This appendix provides information to requiring activities and to procuring activities for tailoring the requirements for procurements of equipments that have submersible applications.

20. REFERENCED DOCUMENTS None.

30. DEFINITIONS None.

40. GENERAL REQUIREMENTS

40.1 Requiring activity responsibilities. Activities responsible for the generation or review of requirements documents, such as operational requirements (ORs) or required operational capabilities (ROCs), should provide the information in the subparagraphs below for equipments or systems with submersible applications. The primary requiring activity originating the submersible requirement should be identified as the submersible requirement coordinator on the routing cover sheets of the requirements document and of the test and evaluation master plan.

40.1.1 Concept of operations/concept of employment. The concept of operations should note those applications that have submersible requirements. The concept of employment should document the operational units/user personnel, number of equipments/systems required, and mission profiles for each submersible application. The mission profiles should illustrate the submergence depth requirements and submersible time-exposure requirements.

40.1.2 Capabilities required. The capability requirements statements should state the submergence depth requirements and the submergence time-exposure requirements.

40.1.3 Concept of support/integrated logistics support (ILS) requirements. The concept of support should identify the organizational concepts for use and first-line maintenance support for submersible applications, especially if the requirements differ substantively from the general application requirements.

40.1.4 Affordability criteria. The affordability limits or cost criteria should identify the cost differential premium allowed (if any) for those equipments designated for submersible applications. The differential premium may be expressed as either a dollar amount (in fixed fiscal-year dollars) or as a percentage of average unit costs. A differential premium will apply if the equipments meeting the submersible requirements are not identical to those meeting the general application requirements.

40.1.5 Acquisition concept. The assumed acquisition concept should be explicitly documented. Since submersible applications are frequently a small number of the total applications, an acquisition concept employing a submersible retrofit kit or a submersible equipment variant may be assumed in lieu of requiring all equipments to meet the submersible requirements.

40.2 Procuring activity responsibilities. Acquisition managers responsible for developing and/or procuring equipments or systems with submersible requirements

should implement and tailor the requirements of this handbook in accordance with the subparagraphs below. The acquisition manager should develop the acquisition strategy in accordance with paragraph 4.3 and be consistent with economic analysis and the requirements document assumptions. Deviations from assumptions of the requirements documents should be cleared with the requiring activity(ies) and supported by cost impact data. All modifications to submersibility requirements should be coordinated with the primary requirement activity for the submersibility requirement.

40.2.1 Specification requirements. The following elements should be incorporated into the equipment specifications:

- mission profile(s).
- submersible depth requirement in accordance with MIL-STD-108.
- submersible time-exposure requirement, if longer than 24 hours per exposure.
- requirement to use separate environmental seals and EMI gaskets, if required (see paragraph 4.2.1).
- display illumination/visibility requirements.
- other specification tailoring items as required by MIL-E-16400 or MIL-E-4158, as appropriate.

40.2.2 Statement of work requirements. The following provisions should be included in the statement of work:

- design analysis in accordance with paragraph 4.1 (cite appropriate design class). If other design analyses are required, the requirements of this handbook can be included as part of the overall design analysis effort, as appropriate.
- the design guidelines (paragraph 4.2) of this handbook should be stated as mandatory (required in implementation); baseline (required to be implemented, except for approved design tradeoffs); or advisory (to be considered in design, but not required).
- the integrated logistic support (ILS) tasks shall include the development of seal maintenance procedures and technical documentation supporting the submersible applications in accordance with the specific requirements of this handbook (paragraphs 5.1.4, 5.1.5, 5.2.4, or 5.3.2, as appropriate).
- system cost analyses, if required, should include costs peculiar to the submersible requirement for acquisitions developing a submersible variant (see 4.3.2).

40.2.3 Contract data requirements. The Contract Data Requirements List (CDRL) should provide the following data items. If these items can be included in a data item already required, only the additional information requirements of this handbook need to be cited.

- the design analysis report should be required in accordance with paragraph 5.4.
- technical documentation in accordance with paragraph 5.1.4, 5.1.5, 5.2.4, or 5.3.2 as appropriate.

40.2.4 Design review requirements. The Preliminary Design Review should include a detailed review of the design analyses conducted to support the submersibility design in accordance with paragraph 4.1. The Critical Design Review should include a detailed review of the design implementation to meet the submersibility criteria. If a Functional Configuration Audit is required, conformance to the design parameters critical to submersible performance should be included.

40.2.5 Test and evaluation requirements. The submersibility requirement should be cited as a critical issue in the Test and Evaluation Master Plan (TEMP). Operational test and evaluation should include one or more of the mission profiles containing submersible requirements.

50. SPECIFIC REQUIREMENTS None.

APPENDIX E

RETROFIT DESIGN ILLUSTRATION

10. GENERAL

10.1 Scope. This appendix provides an illustration of submersible retrofit kit designs. Alternative designs are presented as they might be applied to a single equipment; this presentation will illustrate the tradeoffs of each approach. The AN/PRC-104 Radio set is used as the illustration equipment. It is assumed that all of the technologies discussed are implemented adequately to meet the specifications.

10.2 Purpose. The tradeoff illustrations in this appendix are intended to show the range of design alternatives. This appendix is intended to aid in understanding the application of this handbook; it is not intended to offer comprehensive nor definitive recommendations to specific application requirements. The order of the illustrations should not be construed as a preference or recommendation. The following tradeoff elements have been included in the illustration:

- Submersibility performance
- Kit design cost
- Implementation costs
- Life-cycle cost impact
- Reliability
- Maintainability
- Operator utility

20. APPLICABLE DOCUMENTS None.

30. DEFINITIONS None.

40. GENERAL REQUIREMENTS

40.1 Background.

40.1.1 Equipment description. The AN/PRC-104 is a modern high frequency (HF) radio set that has many design features typical of electronic equipments in general use. Its design characteristics allow many different approaches to the problem of retrofit for submersible applications; therefore, it is a good candidate to illustrate the variety of tradeoffs involved in retrofit kit design. The AN/PRC-104 was designed to be waterproof and weather resistant, so there are design features suitable for submersion and deficiencies for submersion beyond the original design specifications. The AN/PRC-104 consists of three main units: a receiver-transmitter (RT), a radio frequency power amplifier (AM), and a battery pack (PP). These three units clamp together to form the radio set and require connectors between the units for power and signals. The RT unit has a front-panel module consisting of discrete components for mode, frequency set, and volume controls, connectors for audio/data input and output accessories, and windows over the frequency set display. The AM unit has a front-panel module having a mode control and connectors for antennas. Both the RT and the AM have top and bottom covers for ease of maintenance access. The design approach is used throughout a family of equipments that includes the AN/PRC-104.

The modularity and accessibility are design features critical to the entire equipment family. The associated controls and connectors are standard to the family. Extensive use of flexible printed wiring and connectorized modules provide for producibility, reliability, and rapid exchange of modules for repair or mission reconfiguration. These same design approaches are found in many modern electronic equipments in general military use.

40.1.2 Statement of requirements. For purposes of the illustration, operational requirements are defined as follows:

Mission time	8 days/2 hours per day/battery change allowed
Submersibility	300 foot (10 atm)/8-hour exposure/nonoperating/salt water
Temperature	0-50°C operating 15-20°C nonoperating/submerged
Reliability	0.99/no maintenance during mission
Maintainability	echelon 3/less than 2-hour maintenance total before/after mission.

Except for the submersibility requirement, these requirements are within the design capabilities of the AN/PRC-104.

40.1.3 Analysis of susceptibilities.

40.1.3.1 Maintenance access panels. The maintenance access panels on the RT and the AM are too large and flexible for the specified depth. Excessive pressure creates a gap in the O-ring gland associated with each cover.

40.1.3.2 Battery pack. The battery pack terminals must remain isolated from seawater exposure. The seal between the battery pack and the radio set is inadequate for the specified depth. Also, the seal of the spare battery packaging is inadequate.

40.1.3.3 RT/AM interface. The interface connector between the RT and the AM is sealed with an O-ring. This O-ring is normally adequate, but it is susceptible to wear, scoring, chaffing, and other damage that may compromise its integrity.

40.1.3.4 Controls. The front-panel controls are sealed with O-rings. The control shaft seals are adequate if they are not worn excessively. Leakage can also occur around the control bushings if the controls have been installed improperly.

40.1.3.5 External connectors. The external connectors are susceptible to damage if exposed to salt water. Insufficient data exist to determine the susceptibility of the audio connectors to the specified submergence pressures. If the radio set is turned on while submerged (even accidentally), there are control settings that would be potentially damaging to the radio set.

40.1.3.6 Frequency display windows. The display windows are not adequate to withstand the specified depths.

40.1.4 Illustration restriction. This appendix will only analyze the susceptibilities associated with the maintenance access panels.

40.2 "Glop" technology.

40.2.1 Description. "Glop" is a slang term that aptly describes the application of an elastomeric compound to supplement the existing seals. Although several materials might be considered, noncorrosive silicone RTV compound is preferred. The compound must be removed prior to using controls, connectors, or displays; and it must be reapplied if the sealed surfaces are disturbed mechanically for any reason.

40.2.2 Tradeoffs.

40.2.2.1 Cost considerations. The direct costs associated with this technology are minimal. The materials necessary to protect an entire radio set cost only about \$10 (1988). No special apparatus nor tools are required. Life-cycle costs may be increased by maintenance requirements imposed by residual compound.

40.2.2.2 Reliability/maintainability considerations. Since the "glop" is only applied during submerged transit, there is no direct impact on maintenance. Short-term/mission reliability can be enhanced due to the better environmental seal. Long-term reliability may be adversely affected by residual compound and by repeated usage of the compound.

40.2.2.3 Other considerations. The "glop" must be applied to clean, dry surfaces; adequate surface preparation in the field may be difficult to achieve. The compound adheres strongly to the surfaces to which it is applied; this can cause damage to the equipment finishes, leading to corrosion and fungus damage. Residual compound can prevent the proper operation of control shafts, causing additional maintenance and more frequent overhaul requirements. The compound takes time to cure, so its application immediately prior to submergence is usually ineffective and may actually promote damage if the compound is forced past the design seals into sensitive areas of the equipment or component. Time-to-cure limitations may be incompatible with operational usage requirements. The need to apply the compound in the field implies that field personnel must be trained in its proper use and that extra compound must be transported on the mission. The added bulk may not be significant, but the added weight may be as much as 2 pounds.

40.3 Composite materials technology.

40.3.1 Description. Numerous composite materials are available that can provide the requisite added stiffness without an added weight penalty. New access covers can be provided for these materials and can be substituted for the existing aluminum covers. These new covers can be made two-way interchangeable with the existing covers. A carbon matrix or aramid matrix honeycomb design would probably be preferred. The new cover would be plated on one side to maintain shielding effectiveness and to provide some thermal conductivity.

40.3.2 Tradeoffs.

40.3.2.1 Cost considerations. While there are design and fabrication costs, they are low (all requiring units could be outfitted for under \$50K (1988)). Since a kit could be transferred from one equipment to another, relatively few kits are required.

40.3.2.2 Reliability/maintainability considerations. Maintainability would not be affected. Since composites are less thermally conductive than aluminum, the internal operating temperature of the equipment would be higher; higher temperatures mean

lower reliability. The short specified operating times would reduce this impact, and mission reliability would not be compromised. A thermal analysis would be required as part of the kit design.

40.3.2.3 Other considerations. Although the weight would not be increased, the equipment profile would be about 0.37 inch thicker. This would make it undesirable to make the kit a permanent change to the equipment, since there are applications where the units must slide into a tightly fit opening.

40.4 Fluid fill technology.

40.4.1 Description. Fluid fill technology provides stiffness to the covers by filling the internal volume with an incompressible fluid. Candidate fluids include transformer oil and thermal grease.

40.4.2 Tradeoffs.

40.4.2.1 Cost considerations. The implementation costs are relatively low; however, life cycle costs are greatly increased by increased maintenance times.

40.4.2.2 Reliability/maintainability considerations. Maintenance is inhibited by the fluid, and the time required for all maintenance actions greatly increases. Reliability may be increased by lowering internal operating temperatures because of the good thermal conductivity of most candidate fluids. Reliability might be decreased by fluid incursion into inadequately sealed internal components.

40.4.2.3 Other considerations. Some of the best fluids are toxic or carcinogenic and require special handling and disposal.

40.5 Stiffener technology.

40.5.1 Description. Stiffeners can be added to the internal cavity to limit access cover flexing. Several different stiffener designs can be considered employing sheet metal, plastics, or hard rubbers.

40.5.2 Tradeoffs.

40.5.2.1 Cost considerations. The design of a suitable stiffener system is deceptively complex (perhaps a full workyear effort). The design effort requires a precision tolerance analysis of the equipment as produced. Nevertheless, the implementation and life cycle costs can be expected to be relatively low.

40.5.2.2 Reliability/maintainability considerations. Some stiffener designs may interfere with maintenance access. No reliability impact is anticipated.

40.5.2.3 Other considerations. Since external pressures are partially borne by the stiffener system, the stiffener design must avoid transmitting these pressures to sensitive internal components.

40.6 Stiff geometry technology.

40.6.1 Description. This approach replaces the current flat aluminum covers with new covers designed with stiffening structures.

40.6.2 Tradeoffs.

40.6.2.1 Cost considerations. Similar to the composite materials technology, but perhaps 25 percent less costly.

40.6.2.2 Reliability/maintainability considerations. None.

40.6.2.3 Other considerations. A sufficiently stiff cover geometry will add both bulk and weight. The equipment thickness would be increased by perhaps 0.5 inch and the weight increased by a pound.

40.7 Housing redesign option.

40.7.1 Description. This option would repackage the equipment to eliminate the susceptibilities.

40.7.2 Tradeoffs.

40.7.2.1 Cost considerations. The design costs of this option would run several work-years. Implementation costs would be high because the projected number of kits would be too low to amortize tooling and production costs. Life-cycle costs would be increased by the loss of commonality with the logistics and production base of the equipment family.

40.7.2.2 Reliability/maintainability considerations. Maintenance access would probably be significantly less than the current design, thus increasing maintenance times substantially. Reliability need not be impacted; however, a redesign of this magnitude might enable design changes that might increase reliability by as much as 50 percent.

40.7.2.3 Other considerations. The equipment would be much more resistant to the usage environment. Nevertheless, an essentially new equipment has now been created with all of the attendant logistics support and documentation requirements. The new design would probably not be suitable for general applications and would lose the benefits of modularity and commonality with a large equipment pool.

40.8 O-ring and gland redesign option.

40.8.1 Description. This option would provide a new O-ring for each cover combined with a redesigned gland (requiring remachining and refinishing the housings).

40.8.2 Tradeoffs.

40.8.2.1 Cost considerations. The design costs would be moderate, but the implementation costs could run as high as \$1.5K (1988) per unit in implementing the redesigned gland. Life cycle costs would be minimally affected.

40.8.2.2 Reliability/maintainability considerations. No change.

40.8.2.3 Other considerations. None.

40.9 Jacketing technology.

40.9.1 Description. This approach provides an external jacket over the main body of the equipment. This external jacket is thin but stiff and relieves some of the pressure

from the access covers to allow the O-ring glands to remain within their design limits. To minimize bulk and weight, the jacket might be titanium.

40.9.2 Tradeoffs.

40.9.2.1 Cost considerations. The design and implementation costs would be moderate, largely affected by the design requirements necessary to accommodate tolerances from one radio set to another. Life-cycle costs would not be affected.

40.9.2.2 Reliability/maintainability considerations. The jacket would only slightly hinder maintenance access. Reliability would not be affected.

40.9.2.3 Other considerations. The jacket adds bulk and weight. The radio set width profile would be increased by about an inch. The weight would be about a half pound.

50. SPECIFIC REQUIREMENTS None.

APPENDIX F

SEAL MEASUREMENTS

10. GENERAL

10.1 Scope. This appendix reconciles the various measurements of degrees of seal and enclosure encountered in component and equipment specifications.

10.2 Application. This appendix provides information to designers of equipment for submersible applications. The information is intended to aid in interpreting the seal performance of various component items. However, some of the terms discussed in this appendix are used generically and are not formally defined outside of this document; the designer is cautioned to check the actual seal or leakage rate specifications for each component.

20. REFERENCES

20.1 Government documents. The following documents of the issue listed in the current issue (or other issue specified in a contract or order) of the *Department of Defense Index of Specifications and Standards* form a part of this appendix to the extent specified:

Military Standards

MIL-STD-108	Definitions and Basic Requirements for Enclosures for Electric and Electronic Equipment
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-810	Environmental Test Methods and Engineering Guidelines

20.2 Sources of documents. Government documents are available from the Department of Defense Single Stock Point, Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. For specific acquisition functions, these documents should be obtained from the contracting activity or as directed by the contracting officer.

30. DEFINITIONS

30.1 Leakage rate. The measure of seal performance is leakage rate. For specific definitions, see MIL-STD-202 METHOD 112 and MIL-STD-810 METHOD 512.

30.2 Degrees of enclosure. Degrees of enclosure are defined in MIL-STD-108. MIL-STD-108 provides definitions for the following terms (terms that imply some degree of seal or submersible performance are denoted by *):

- airtight—*
- drip proof
- dust-ignition proof
- dust proof (see MIL-STD-810 METHOD 510)
- dust-tight (see MIL-STD-810 METHOD 510)
- explosion proof (see also MIL-STD-810 METHOD 511)
- hermetic—*
- open and open, protected
- splash proof and splash proof, protected

spray tight—*
submersible and open-submersible—*
totally enclosed
watertight—*

30.3 Immersible. Immersible items are capable of withstanding immersion (covered by fluid) in a test such as MIL-STD-202 METHOD 104 (for components) or MIL-STD-810 METHOD 512 (for equipments) without detectable effects.

30.4 Moisture proof. Moisture-proof components are sealed against the effects of high humidity and extreme temperatures. These effects include moisture absorption, material breakdown, insulation breakdown, and film formation compromising insulation resistance. The degree of seal does not imply any degree of submersibility, but only a mechanical approach toward achieving moisture resistance (capability to withstand a test such as MIL-STD-202 METHOD 106). Nevertheless, moisture-proof components are normally also immersible.

30.5 Resilient. Components that have specific design features that improve reliability in severe environments (vibration, shock, high temperature, high humidity, corrosive atmospheres) are termed resilient. Resilient components are not necessarily submersible (refer to the seal requirements of the individual component specification).

30.6 Shaft/toggle sealed. Shaft sealed and toggle sealed are terms used in many control component specifications to describe a combined performance of explosion proof and submersible—15 feet. The terms only apply to the seal through the control shaft or toggle to the interior of the control; the seal between the control and mounting panel is not specified.

30.7 Environmentally sealed. Environmentally sealed components are hermetic and environmentally resistant.

30.8 Environmentally resistant. Environmentally resistant components are sealed, but not hermetic, and are resistant to fluids, temperature cycling, vibration, shock, and humidity.

30.9 Fluid resistant. A component that is not deteriorated by exposure to various fluids is termed fluid resistant. Fluid resistance does not imply submersible performance.

40. GENERAL REQUIREMENTS

40.1 Submersible performance requirements. There are many mission scenarios requiring submersible performance. However, there is no standard time of exposure, depth of exposure, or allowable leakage that might be inferred from these scenarios. For purposes of this document, two levels of submersible performance are discussed based upon an assumed standard mission.

40.1.1 Standard mission. The standard mission shall include 24 total hours of submersion at the specified depth. The mission may take up to 30 days, but no maintenance will be performed inside the equipment until after the mission is over. The equipment submersion may be at any time during the mission and at any depth as long as the total submersion time does not exceed 24 hours and the submersion depth does not exceed the specified depth.

40.1.2 First criterion. There shall be no evidence of leakage after 24 hours of exposure at the specified depth. Evidence of leakage shall include water or salt deposits internal to the equipment. This criterion is estimated to be at least 5 times more stringent than the criterion of paragraph 40.1.3 at standard temperatures (20 to 25°C). If temperature cycling is incorporated into the test method, this criterion can be over 400 times more stringent than that of paragraph 40.1.3.

40.1.3 Second criterion. There shall be no more than 4 cm³ seawater per cubic foot (or 28,300 cm³) of enclosed volume per 24 hours of exposure at the specified depth if (1) the water has no immediate effect on the equipment and (2) the equipment can operate reliably in the extremes of temperature and humidity. The rationale for this criterion is practical. Four cubic centimeters of water are about the quantity required to raise the relative humidity of 1 cubic foot of air from 50 percent at 21°C to saturation at 49°C. The 49°C value is reasonable for an internal operating temperature, especially for equipments exposed to high temperature and solar radiation effects. Under many normal operating conditions, leakage is not detectable at this leakage rate because all of the water is evaporated to the equipment interior.

40.1.4 Leakage tolerance. Equipments that must be sealed often have capabilities beyond the limits for which they are qualified because the seal design has practical structural and material properties exceeding the qualification requirements. In addition, seal designs are inherently better in sealing static members than for moving members. Many sealed items, like toggle-sealed switches, are capable of movement, but are moved under normal (nonusage) submersion circumstances. Therefore, these items can be applied well beyond their normal specifications for seal. If the items are designed or treated so that they are moisture-resistant internally, the second criterion (40.1.3) of submersible performance may be applied rather than the first criterion (40.1.2). All of these factors may substantially increase the leakage tolerance and the subsequent submersible performance.

40.2 Leakage rate measures. There are two standard measures of leakage rate used in specifying seal performance.

40.2.1 Component-based measures. MIL-STD-202 METHOD 112 and many other component-based test methods use the quantity of dry air at 25°C in atmospheric cubic centimeters per second (atm-cm³/s) at a 1-atmosphere-differential pressure across the seal; all measurements are converted to be equivalent to this standard.

40.2.2 Equipment-based measures. MIL-STD-810 METHOD 512 and other equipment-based test methods use the quantity of water (usually in cubic centimeters) measured per cubic foot of enclosed volume for the specified time and depth of immersion or submersion. There are more variables for comparing seal performance using the equipment-based methods, but the tests are more relevant to operational requirements.

40.2.3 Measurement standard. A standard measure of leakage rate is necessary in order to reconcile component specifications and equipment specifications for submersible applications. This requires baseline assumptions.

40.2.3.1 Assumed standard pressure. Since leakage rate is directly proportional to pressure, it is most convenient to assume a 1-atmosphere-differential pressure.

40.2.3.2 Assumed standard temperature. The actual leakage rate is temperature dependent, but the effects of temperature are small for conditions encountered in submersible applications. For purposes of consistency with existing specifications, 25°C is the assumed temperature.

40.2.3.3 Assumed enclosed volume. The enclosed volume for components is usually considered in three ranges:

- less than 0.01 cm³.
- less than 0.4, but over 0.01 cm³.
- over 0.4 cm³.

In addition, typical man-packable equipments enclose about 1400 cm³ and typical hand-held equipments enclose about 25 cm³. It is convenient to assume an enclosed volume at 45 cm³; equipment-based measures and component-based measures become equivalent at about 45 cm³, all other factors being constant.

40.2.3.4 Measurement units. The standard leakage rate for submersibility (L_s) shall be expressed in cubic centimeters of seawater per day (24 hours) at the assumed standards for temperature, pressure, and enclosed volume.

40.3 Reconciliation of standards.

40.3.1 Reconciliation to MIL-STD-202.

40.3.1.1 Seal—METHOD 112. The equivalent standard leakage rate (L_a) for MIL-STD-202 METHOD 112 and similar test methods shall be reconciled to the standard leakage rate of paragraph 40.2.3.4 by the following expression:

$$L_a \times 1.08 \times 10^6 = L_s$$

40.3.1.2 Immersion—METHOD 104. MIL-STD-202 METHOD 104 tests seal integrity without providing a measure of leakage rate. The immersible performance of items under test are dependent on their seal and also upon the ability to measure internal parameters that indicate leakage. If suitable measurements are available, the maximum detectable standard leakage rate (per 40.2.3) is estimated for each test condition. Since the test sensitivity is the controlling factor, the actual leakage rate may or may not be substantially lower.

Test condition A 9.3 X 10⁻² cm³/day (Note: Value may vary depending on local water conditions.)

Test condition B 2.9 X 10⁻³ cm³/day

Test condition C 2.9 X 10⁻⁴ cm³/day

40.3.2 Reconciliation to MIL-STD-810. MIL-STD-810 METHOD 512 does not directly measure leakage rate. Also, the test method is subject to tailoring to specific equipment requirements. A leakage rate may be measured if the test method is used without modification and employs all recommended parameters, and if the second criterion (40.1.3) is used. If L_i is the measured leakage in cm³ of water per cubic foot of enclosed volume, L_i shall be reconciled to L_s (40.2.3) by the following expression:

$$L_i \times 2.67 = L_s$$

Notes:

1. Divide the actual leakage amount by the actual enclosed volume (in cubic feet) to obtain Li.
2. If an immersion depth other than 1 meter is used, divide the actual leakage amount by the immersion depth (in meters) to obtain Li.
3. If the first criterion (40.1.2) is used and condensation is barely detectable, use $0.01 \text{ cm}^3/\text{ft}^3$ for Li and a maximum standard leakage rate, Ls, of $0.002 \text{ cm}^3/\text{day}$.

40.3.3 Reconciliation to MIL-STD-108. The following degrees of enclosure have a maximum detectable standard leakage rate (per 40.2.3). The maximum detectable leakage rate is determined by the sensitivity of the test. Some equipments may be capable of substantially better submersible performance than that to which they are qualified. Equipment qualified to 1 degree of enclosure may have a greater acceptable level of submersible performance under less stringent operational scenarios than that of 40.1.1, under these conditions: (1) if the operational submersion times are substantially less than 24 hours or (2) if the users are capable of properly opening, drying, and resealing the equipment after each submersion.

40.3.3.1 Airtight. Airtight is defined as no more than a 6-percent change in a 10-psi pressure differential in 24 hours (after correcting for temperature and barometric pressure). This is equivalent to a standard leakage rate of $4.99 \text{ cm}^3/\text{day}$.

40.3.3.2 Hermetic. Hermetic limits are defined by the individual equipment or component specifications. The highest commonly encountered leakage rate is 1×10^{-6} per MIL-STD-202. This is equivalent to a standard leakage of $0.108 \text{ cm}^3/\text{day}$. More stringent hermetic requirements have proportionally lower maximum leakage rates.

40.3.3.3 Spray tight. The maximum standard leakage rate for spray tight equipment is $29 \text{ cm}^3/\text{day}$. However, the equipment seals may not be able to withstand significant overpressures.

40.3.3.4 Watertight. The maximum standard leakage rate for watertight equipment is $2.7 \text{ cm}^3/\text{day}$.

40.3.3.5 Submersible-(depth). Submersible—(33 feet) (for salt water) and submersible—(33.9 feet) (for fresh water) are equivalent to a standard leakage rate of $0.01 \text{ cm}^3/\text{day}$. (Lower leakage rates cannot be easily distinguished from condensed humidity.) Greater specified depths lower the maximum standard leakage rate proportionally.

50. SPECIFIC REQUIREMENTS None.

**RECOMMENDED CHANGES TO MILITARY STANDARDS
AND SPECIFICATIONS**

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Recommended Changes to MIL-STD-108E with NOTICE 1 dtd 19 SEP 1985

PROBLEM: MIL-STD-108 specifies degrees of enclosure for electronic equipments. The special warfare community requires enclosures submersible to depths compatible with current operational requirements; however, the standard defines only three depths for submersibility—15 foot, 50 foot, and 1600 feet—which do not provide intermediate operating depths. Also, some equipments are not required to operate when submerged, but merely to survive submergence exposures without additional protection. MIL-STD-108 lacks the flexibility to tailor to these requirements. Guidance is not provided toward the tailoring of individual equipment specifications to work around these deficiencies.

SUMMARY OF RECOMMENDED CHANGES: The recommended changes add the capability of tailoring requirements and add defined depths of submergence to facilitate use.

DETAILED RECOMMENDED CHANGES:

Page 7, Table I, first column (Degree of Enclosure): change "Submersible (15 foot)" "Submersible (50 foot)" and "Submersible (1600 foot)" to read "Submersible (specified depth)".

Page 7, Table I, first column (Degree of Enclosure): change "Open-submersible (15 foot)" "Open-submersible (50 foot)" and "Open-submersible (1600 foot)" to read "Open-submersible (specified depth)".

Page 10, Table III, first column (Enclosure): consolidate the three depths of "submersible" and "open-submersible" into one block titled "Submersible (specified depth)/Open-submersible (specified depth)".

Page 10, Table III, second column (Submergence Depth (feet) or Equivalent Pressure (psi)), three blocks corresponding to "submersible" depths: replace three blocks with single block reading "specified depth (equivalent pressure shall be computed at 0.4338 psi per foot of specified depth for freshwater or 0.4450 psi per foot of specified depth for seawater) standard specified depths (equivalent pressures) are as follows:

- 15 foot (6.5 psi fresh/6.7 psi sea)
- 50 foot (21.7 psi fresh/22.3 psi sea)
- 150 foot (65.1 psi fresh/66.8 psi sea)
- 300 foot (130 psi fresh/134 psi sea)
- 1600 foot (694 psi fresh/712 psi sea)

Page 10, Table III, fourth column (Test Details), block corresponding to "submersible": add the following in block or as note: "Equipment specified as nonoperating submersible shall be tested in the modes intended for submerged transit. Parts which are intended for submerged use only as part of an equipment shall be tested using a suitable enclosure providing a normal mounting configuration."

Page 11: add new paragraphs as follows:

"5.1.2 Electrical tests. When parts having an internal electrical function (such as switches or connectors) are tested to submergence requirements (TABLE III) of this

standard, saturated salt water solution may be used as the submergence medium in lieu of freshwater or seawater to facilitate electrical testing to detect leakage. Appropriate electrical tests (such as insulation resistance, contact resistance, etc.) should be performed before and after the submergence exposure; changes in the appropriate electrical parameter shall be evidence of enclosure failure. Care shall be taken to clean and dry the part prior to the final electrical tests.

5.2 Tailoring. Equipment and part specifications citing this standard must specify the degree of enclosure for the required operating conditions in accordance with the definitions provided herein. When the degree of required enclosure differs significantly between operating and nonoperating conditions, separate specifications and tests shall be cited; only the most stringent test condition need be tested if the enclosure is not materially nor functionally altered between the operating and nonoperating conditions."

Recommended Changes to MIL-STD-202F with NOTICE 8

PROBLEM: MIL-STD-202 METHOD 112D (SEAL) is intended to test seal conditions built into individual components, not conditions of enclosure with those components functioning as a part of an overall enclosure design. That is, MIL-STD-202 METHOD 112D tests the component design/production processes and not design factors that bear on the use of the component. MIL-STD-202 METHOD 104A (IMMERSION) is applicable to test for damage after a submersion but does not provide a coordination of requirements with enclosure design requirements. Therefore, there is no direct correlation between the component specifications and use of the component in a design.

SUMMARY OF RECOMMENDATIONS: The detailed recommendations refer the component specification to MIL-STD-108 and provide for a reconciliation of component and usage requirements.

DETAILED RECOMMENDED CHANGES:

MIL-STD-202 METHOD 112D, page 1: add new paragraph as follows:

"1.2 Enclosure specifications. The following enclosure specifications shall be tested in accordance with MIL-STD-108: "spray tight," "watertight," "submersible," and "open-submersible." MIL-STD-202 METHOD 104A may be used to test requirements of "spray tight" or "moisture proof." Components qualified to this method, Test Condition C, for standard conditions, will pass requirements for "submersible (150 foot)" (MIL-STD-108) when properly mounted. "

MIL-STD-202 METHOD 104A, page 1: add the following:

"5. NOTES. This method does not test for requirements of enclosure, such as "watertight" or "submersible"; for these requirements, test in accordance with MIL-STD-108. This method may be used as a substitute test for MIL-STD-108 "spray-tight" requirements."

Recommended Changes to MIL-B-5423C

PROBLEM: MIL-B-5423C specifies the general requirements for molded boots and seals used to add dust-tight and watertight performance to components that do not have that degree of environmental integrity. Numerous combinations of boot seals and components have been tested successfully to submergence depths of 300 feet. The 300-foot depth greatly exceeds the specification test limit of MIL-B-5423 parts, which is 15 psi (which corresponds roughly to a 33-foot water depth). The requirements for standard components to withstand greater operational depths suggest that flexibility is required in supporting military standards and specifications to allow designs to be easily tailored to the operational requirements of the greater special warfare community. MIL-B-5423 parts are needed that can withstand submergence depths up to 300 feet.

SUMMARY OF RECOMMENDATIONS: The recommended changes add submergence classifications to MIL-B-5423. These classifications will simplify the qualification of component designs to meet special warfare submergence requirements.

DETAILED RECOMMENDED CHANGES:

Page 1, paragraph 1.2, add the following:

"Environmental Classes:

- Dust-tight
- Watertight
- Submersible (15 foot)
- Submersible (50 foot)
- Submersible (150 foot)
- Submersible (300 foot)"

Page 2, under MILITARY STANDARDS, add MIL-STD-108—Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment.

Page 3, paragraph 3.6, retitle from "Watertightness" to "Watertightness and Submersibility"

Page 6, add new paragraph as follows:

4.5.5 Extension of qualification. Products qualified to the one environmental class shall be considered qualified to all lesser environmental classes. Products qualified as "submersible" shall be considered qualified as submersible for all lesser design depths, for watertight, and for dust-tight. Products qualified as "watertight" shall be considered qualified as dust-tight.

Page 11/13, replace paragraph 4.7.3 as follows:

4.7.3 Watertightness and Submersibility.

4.7.3.1 Preliminary. Boots shall be mounted on the applicable switches, dummy switches, circuit breakers, or test plugs (all without an internal bushing seal) (see 4.4.1), and installed on a test enclosure (qualified to at least double the test depth). A mechanism shall be provided for operating the switches, circuit breakers, or test plugs.

4.7.3.2. Test conduct. The boots shall be submerged and tested in accordance with MIL-STD-108 at the specified condition for the specified environmental class; the switches, circuit breakers, or test plugs shall be operated a minimum of 25 cycles while at maximum submergence pressure. The rate of pressurization shall not exceed 5 pounds force per square inch per minute to the maximum specified pressure; the rate of depressurization shall not exceed 30 pounds force per square inch per minute.

4.7.3.3 Test criterion. During the test, boots shall be observed for evidence of water leakage into the test enclosure or for a continuous stream of bubbles. (See 3.6.)

4.7.3.4 Applicability. This test shall be applied before and after the Endurance test (4.7.8)."

Recommended Changes to MIL-S-8805D

PROBLEM: A variety of MIL-S-8805 switch components are environmentally sealed and capable of surviving submersion exposures of several hundred feet. MIL-S-8805 defines six levels of enclosure design, which include "unsealed," "dust-tight," "water-tight," "resilient," "hermetic," and "splashproof." Of these levels, all are defined and tested in accordance with MIL-STD-108, except "resilient" and "hermetic," which are referenced to and tested in accordance with MIL-STD-202 METHOD 112. Resilient and hermetic enclosure designs are meaningful in terms of switch reliability and have implications in overall enclosure design of end items. However, these terms are not defined in a manner consistent with design applications.

SUMMARY OF RECOMMENDATIONS: The recommended changes provide consistency between MIL-S-8805, MIL-STD-108, and MIL-STD-202. The changes will enable switch specifications to be designed to submersible requirements without causing design changes to parts in manufacture.

DETAILED RECOMMENDATIONS:

Page 1, paragraph 1.2.1, Table I, add enclosure design "7—submersible ()".

Page 1, paragraph 1.2.1, add the following: "When a switch design meets multiple enclosure design requirements, the enclosure design symbol for the most stringent seal requirement shall be used."

Page 7, add new paragraph 3.7.6 as follows:

"3.7.6 Submersible () (applicable to enclosure design 7). When switches are tested as specified in 4.8.3.6, there shall be no water leakage through the panel seal or into the switch as determined by visual inspection or by electrical test of contact resistance, as specified in the individual specification sheet. When a switch is designated as submersible, the submersible depth capability shall be in accordance with MIL-STD-108."

Page 18, add new paragraph 4.8.3.6 as follows:

"4.8.3.6 Submersible () (applicable to enclosure design 7). With the switch mounted by its normal means, the switch shall be subjected to the submersible (specified depth) test of MIL-STD-108. During the test, the switch shall be subjected to 20 cycles of actuation without electrical load.

Page 36, paragraph 6.4.12.4, add the following: "Resilient switches are intended to supply increased contact reliability when applied in unsealed enclosure designs."

Page 36, paragraph 6.4.12.5, add the following: "Hermetic switches are intended to supply increased contact reliability over resilient switches when used in unsealed enclosure designs; hermeticity may also be required for operation in certain explosive environments."

Page 36, add new paragraph 6.4.12.7 as follows:

"6.4.12.7 Submersible (specified depth). Submersible switches are designed to seal the panel and contact areas to meet the requirements of 3.7.6."

**KEY TECHNOLOGIES FOR SUBMERSIBLE
ENVIRONMENTS**

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ENCLOSURE TECHNOLOGIES

1. Open-submersible packaging
Advantages: light weight; low procurement cost
Disadvantages: corrosion control, seal requirements for all components, continuing maintenance requirements, possible thermal design problems, requires developing seal specifications for a variety of component parts and test-qualifying those parts
2. Composite materials/matrix geometries
Advantages: adaptable to modification kits, minimal weight impact
Disadvantages: cost per item, difficulty in producing complex shapes, adaptations must be developed for thermal design and shielding performance
3. Structural geometries (cylindrical/spherical packaging)
Advantages: low weight for packaging volume, minimal sealing problems
Disadvantages: incompatible with existing designs, and design tradeoffs driven by majority user requirements (each design becomes a custom package with associated high costs); reduces accessibility for maintenance and reduces practical areas available for displays, controls, and connectors
4. "Glop" technology (sealants applied to exterior surfaces and over sensitive components)
Advantages: low cost; field implementable
Disadvantages: susceptible to damage, possible damage to connectors and other sensitive components, must be accomplished for each mission/transport phase—equipments may be damaged if improperly applied

CONNECTOR TECHNOLOGIES

Existing connector types are recommended with the caveat that protective environmental caps be qualified for submergence and that environmentally resistant connector options include appropriate submergence specifications.

Nonenvironmental connectors, such as battery connections, are recommended to be protected by gasketing in the enclosures.

DISPLAY TECHNOLOGIES

Existing display technologies are recommended with protection to be provided by windows designed as part of the enclosure.

CONTROL TECHNOLOGIES

1. Totally sealed controls
Advantages: compatible with open-submersible
Disadvantages: qualification test costs; component availability
2. Membrane switch technology
Advantages: balanced design performance including total environmental seal, totally integrated panel technology provides for displays as well as

controls, very high reliability, low per-unit cost (excluding NRE), multi-purpose controls are easily implemented

Disadvantages: each panel is a custom design with high nonrecurring engineering costs, some control functions operate differently (i.e., volume control function becomes discrete steps rather than continuously variable), standards have not been developed to guide the acquisition of the technology, the required control logic may increase power drain

3. Magnetic switch technology

Advantages: alternate action and momentary action available, high reliability, advantages similar to membrane switch technology

Disadvantages: immature technology, miniaturized components yet to be developed, unknown cost impacts until the technology is developed more fully

4. Shaft seals and boots

Advantages: components are already available and inexpensive, adaptable to modification kits, easy to maintain

Disadvantages: seals are susceptible to damage, maintenance is required